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ADVANCED ENERGY TECHNOLOGY DEVELOPMENT IN NEW MEXICO

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BEFORE THE

COMMITTEE ON ENERGY AND NATURAL RESOURCES UNITED STATES SENATE

ONE HUNDRED SEVENTH CONGRESS

SECOND SESSION

ON

ADVANCED ENERGY TECHNOLOGY DEVELOPMENT IN NEW MEXICO

DECEMBER 3, 2002

ALBUQUERQUE, NM

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ADVANCED ENERGY TECHNOLOGY DEVELOPMENT IN NEW MEXICO

TUESDAY, DECEMBER 3, 2002

U.S. SENATE,
COMMITTEE ON ENERGY AND NATURAL RESOURCES,
Albuquerque, NM

The committee met, pursuant to notice, at 10:00 a.m. at Albuquerque Technical Vocational Institute Work Force Training Center, 5600 Eagle Rock Road, NE, Albuquerque, New Mexico, Hon. Jeff Bingaman, chairman, presiding.

OPENING STATEMENT OF HON. JEFF BINGAMAN, U.S. SENATOR FROM NEW MEXICO

The CHAIRMAN. Thank you all for coming this morning. This is a field hearing of the Senate Energy and Natural Resources Committee. We're going to highlight the roles that some of our companies here in New Mexico, and also our national laboratories are playing in shaping the Nation's energy future.

Obviously, this hearing is not able to cover the whole spectrum of areas that people are working in, but we are going to explore recent technological advances in two areas that are key to our energy future.

The first of these is the Next Generation Lighting Initiative. The Energy Information Administration calls lighting the most important individual energy use in the commercial sector. The lighting accounts for something over 20 percent of commercial primary energy consumption, which makes lighting a technological area, and a good new idea can save a great deal of energy. Worldwide lighting products are about a $40 billion a year industry, so a good new idea also could do a great deal for our economy. Using LEDs, light emitting diodes, to produce white light may provide the technological leap that we are looking for.

Advanced LED technology involves the use of solid state diodes and conductive polymers to produce white light twice as efficient as fluorescent lights and ten times more efficient than traditional incandescent lights. This LED technology has the potential to displace our traditional lighting industries, which are based on the technologies that Thomas Edison invented more than 100 years ago, so we look forward to hearing from witnesses about recent advances in this area.

The second technology we're going to hear about today is fuel cell technology. Fuel cells have been around for years. They were used to provide the power for the Apollo missions in the 1960's. More recently, attention has focused on the promise that fuel cells offer as

an alternative to the internal combustion engine; however, before fuel cells can be widely used in vehicles and other applications, manufacturing costs need to be brought to competitive levels; questions of producing hydrogen need to be adequately answered; choice of fuels to power fuel cells and how that fuel can be delivered to the consumer; how it can be stored in a way that makes sense economically.

We have an excellent group of witnesses today. First panel, we start with a representative from the Department of Energy, Mr. Richard Moorer, who is the Deputy Assistant Secretary for Technology Development in the Office of Energy Efficiency and Renewable Energy, from the Department of Energy. After his testimony, Dr. Al Romig, who is the Vice President of Sandia National Labs Science and Technology Partnerships. He is in charge of the science and technology partnerships at Sandia National Lab. And Dr. Charles Becker, who is the manager of LEDs for Lighting Program for GE Global Research. And we will hear from all of them.

And in the second panel, Dr. Ken Stroh, who is the Manager of Transportation and Fuel Cell Programs at Los Alamos; Dr. Mark Hampden-Smith, who is representing Superior MicroPowders at Motorola's—their partnership with Motorola, and Dr. Ned Godshall, who is the CEO of MesoFuel, Inc., here in Albuquerque.

So we have an excellent group of witnesses, so why don't we just start in, and I will have—this is our first panel up here. I'll have a few questions after we hear from the three panelists on the first panel.

Mr. Moorer, why don't you start and give us your views on these issues and what the Department of Energy is doing about it.

STATEMENT OF RICHARD F. MOORER, DEPUTY ASSISTANT SECRETARY FOR TECHNOLOGY DEVELOPMENT, OFFICE OF ENERGY EFFICIENCY AND RENEWABLE ENERGY, DEPARTMENT OF ENERGY

Mr. MOORER. Thank you, Mr. Chairman, for this opportunity to testify here today. This is a most appropriate venue to discuss fuel cells and advanced lighting technologies because the Department of Energy's two national laboratories in New Mexico, Los Alamos and Sandia, each play an important role in developing these technologies.

I'll first discuss fuel cell technology, which is fundamental to FreedomCAR, our flagship research and development initiative, to reduce the nation's dependence on foreign oil and dramatically change how we power our cars and trucks, and then turn to the subject of solid state lighting.

I have provided some slides for the record; there are some copies on the back table, and I will go through those as I make my remarks.

On slide 2, I speak to the most striking feature of our transportation system: its nearly complete dependence on petroleum as an energy source. Petroleum is used to satisfy 97 percent of America's transportation energy needs, and roughly 55 percent of our petroleum is imported from abroad.

There is an expanding gap between declining domestic oil production and our increasing demand. As you can see, opening the

coastal plain of the Arctic National Wildlife Refuge to exploration would clearly help, but that alone would not close the gap.

Research and development to improve auto and truck efficiency would also help, but again, it would not close the gap. Indeed, both taken together would not close the gap.

In response to this challenge, we have shifted our R&D technology portfolio to higher risk, higher reward strategies leading to the development and use of fuel cells and domestically derived hydrogen that could one day eliminate our need for foreign petroleum.

Slide 3: On January 9, 2002, Secretary Abraham, joined by top leadership——

The CHAIRMAN. Does everyone have a copy of these slides? Are there extra copies that anyone has around here, that we could pass out?

Mr. MOORER. I believe they're on the back table.

The CHAIRMAN. Okay. All right. Go ahead. You were talking about slide 3.

Mr. MOORER. Slide 3. I have tried to make it easier for you so that if you don't have slides, you'll at least get the message.

Slide 3 speaks to the signing by Secretary Abraham and joint top leadership from General Motors, DaimlerChrysler and Ford, announcing FreedomCAR at the North American International Auto Show in Detroit.

Slide 4 speaks to the FreedomCAR partnership. The "CAR" in FreedomCAR stands for "cooperative automotive research," and the freedom concept represents our fundamental long-term goals for this program; freedom from petroleum dependence, freedom from pollutant emissions, freedom for Americans to choose the kind of vehicle they want to drive, and to drive where they want, when they want; and freedom to obtain fuel affordably and conveniently. This is a dramatic far-reaching vision, one that requires new technology.

Slide 5 speaks to our strategic approach in this partnership. The first element of our strategic approach is to develop technologies to enable mass production of affordable hydrogen-powered fuel cell vehicles and assure the hydrogen infrastructure to support them, but neither industry or government, working alone, can overcome the significant technical barriers to a hydrogen fuel cell future in any reasonable time frame; therefore, we must work in partnership.

The automotive partnership that was in place in the past, the Partnership for a New Generation of Vehicles, or PNGVs, had some successes, and we are certainly not abandoning those successes or the collaborations it fostered. In fact, similar research elements of PNGV are embodied in the second element of our approach; to continue support for hybrid technologies and advanced materials that can dramatically reduce oil consumption and environmental impacts in the nearer-term before fuel cells can become competitive.

One of the problems of PNGV was its narrow focus on a production prototype of family sedans; therefore, the third element of our strategic approach is to develop technologies applicable across a wide range of passenger vehicles.

Slide 6 speaks to the technological risks that we face. If hydrogen fuel cells are to succeed in the marketplace, they must equal or better the performance of today's vehicles, including range, durability,

start-up time, acceleration and safety. Moreover, these technologies must be integrated in vehicles that can be manufactured in quantities of millions per year at a cost competitive with current technologies.

Since fuel cell vehicles run on hydrogen, which is not yet available at the corner gas station, elements of our technology portfolio are focused on making hydrogen production, transportation, storage, and refueling safe and affordable. We must also work towards the development of logical regulations, codes and standards governing the transportation and use of hydrogen.

The next slide announces our national hydrogen energy roadmap, and to this end, we have been working on this roadmap. The secretary announced it on November 12, 2002, and it will guide us in a collaborative effort with industry, academia and our national laboratories towards the barriers that this technology faces.

Los Alamos National Lab and Sandia National Lab, in particular, have made significant contributions to reducing the cost of fuel cells and to developing hydrogen storage materials, respectively.

Slide 8 speaks to the work that's been happening at Los Alamos. They have been a pioneer in the development of PEM fuel cell technology. Los Alamos researchers have steadily decreased the platinum requirement of fuel cells, which has led to a reduction in projected cost of mass-produced fuel cell systems by an order of magnitude from around $3,000 per kilowatt, 10 years ago, to around $300 per kilowatt today. Another order of magnitude reduction to $30 a kilowatt is necessary to be competitive with the cost of current internal combustion engines.

Slide 9 highlights the work at Sandia National Laboratory, where they have made key contributions to the development of hydrogen storage materials. Hydrogen storage lies in the critical path to our success for our hydrogen economy. Current technology relies on high-pressure tanks that take up a lot of space in fuel cell vehicles, reducing the trunk space and the vehicle range. We are seeking hydrogen storage systems that enable high storage capacity at low pressure.

This slide illustrates the progress made in increasing hydrogen storage capacity of materials that have been developed by Sandia National Laboratory. DOE's target is to triple the capacity of most existing metal hydride storage systems. We are also working to develop PEM fuel cells as a stationary distributed power source.

Mr. Chairman, my boss tells me that you're somewhat of an expert in the area of distributed energy, and so I'm going to forego that and skip to slide 12.

I would like to make the point, though, that there is important synergy between the transportation and stationary fuel cell markets and R&D activities. For fuel cells to succeed in establishing near-term market success, our R&D must address these critical barriers associated with stationary and affordable power applications.

Now I'd like to turn to the subject of the other focus of this hearing; advanced lighting.

We consumed an estimated 96.3 quadrillion BTUs of primary energy in the United States in 2001, more than a third of which, or 35 quads, were used to generate electricity.

Slide 14 speaks to the energy consumption for lighting. Lighting consumes about 22 percent of the total electricity used in the United States, and the lion's share of energy consumption for lighting is in the commercial sector.

Today, much of our lighting is relatively inefficient. My daughter once had an Easy-Bake Oven that she used to bake cakes, and it was a terrific demonstration that incandescent lights can produce an awful lot of heat as well as light; a testament to their inherent inefficiency. Incandescent light sources only produce about 15 lumens per watt.

Compact and tubular fluorescent light bulbs with electronic ballasts are more efficient and produce far less heat than incandescent light bulbs. These light sources produce about 90 lumens per watt. We believe it is possible to produce higher quality lighting using advanced, solid-state technology that could deliver as much as 150 lumens per watt, a 70 percent improvement over the best fluorescent lighting available today.

Slide 15 speaks to the various solid-state innovations that we have seen. The transition to solid-state technology in lighting would mirror similar advances made in other fields. Transistors have replaced vacuum tubes in radios and consumer electronics, solid-state screens have replaced cathode ray tubes in computers and television sets, and solid-state lighting is starting to be employed in certain niche applications.

Slide 16 speaks to the various solid-state lighting sources. Within the field of solid-state lighting, or optoelectronics, there are three general technical subgroups, each of which can offer search advantages for a range of applications.

Light-emitting diodes, or inorganic LEDs, are used today in signs and single lighting applications such as traffic lights and pedestrian crossing signals.

Organic light-emitting diodes, or OLEDs, are a flexible organic-based cousin of LEDs. Not yet achieving the same brightness as LEDs, current OLED development is focused on large displays, personal display devices and instrumentation.

Other novel solid-state lighting includes light-producing structures, such as vertical cavity surface emitting lasers, or "vixels." They do not fit conveniently in any of the prior categories. We can find successful commercial applications of this technology in telecommunications, and in performing critical medical and scientific research.

Slide 17 shows some examples of solid-state lighting applications today. You may be familiar with the NASDAQ sign in Times Square powered by more than 18 million red, blue and green LEDs. Just like your television set, when perceived from a distance, this mix of color produces white light and various combinations of each, which can produce any color desired.

Another display technology is pictured on this slide. This is an example of a prototype OLED display that may eventually replace the computer screens and TV monitors we have today. Based on the same principle of the three colors, but at a far greater resolution, we find the technology starting to be used today in some mobile phones and car radio displays.

If research in this area is successful, these OLED displays could be formed into ceiling tiles installed in our offices, being both the fixture and the light source, emitting white light or any other color that we want. This lighting source can be infinitely dimmable with no penalty in efficiency or life. This makes it a superb match for a building energy management system.

My last slide, slide 18, speaks to the solid-state roadmapping that we've been doing, and it points out that there are both cost and technical barriers to the use of these technologies in the white light market.

To help address these barriers, our office is conducting lighting research and development through our building technologies program. Last year, we spent about $6 million in pursuit of this mission. In an effort to identify the technology path we should follow to enhance and accelerate the development of white light from solid-state sources, we convened eight workshops bringing together key stakeholders from industry, academia and the national labs.

We believe solid-state lighting potentially offers the most efficient means of converting electrons into photons. Thus far, industry has focused on signals and displays. Continued research into the uses of solid-state lighting for general illumination could help us maintain technological leadership and provide us with an important tool in improving the nation's energy efficiency identified in the President's national energy policy as a national priority. We are exploring ways to accelerate this work for a stronger, better-coordinated, public-private partnership.

Thank you, Mr. Chairman, for the opportunity to offer these views today, and I would welcome any questions the committee might have today or in the future.

[The prepared statement of Mr. Moorer follows:]

PREPARED STATEMENT OF RICHARD F. MOORER, DEPUTY ASSISTANT SECRETARY FOR TECHNOLOGY DEVELOPMENT, OFFICE OF ENERGY EFFICIENCY AND RENEWABLE ENERGY, DEPARTMENT OF ENERGY

Mr. Chairman, I appreciate this opportunity to discuss advanced fuel cell and lighting technology.

This is a most appropriate venue to discuss these subjects, because the Department of Energy's two National Laboratories in New Mexico—Los Alamos and Sandia—each play an important role in the development of these technologies.

I will first discuss fuel cell technology, specifically the polymer electrolyte membrane or PEM fuel cell that is the key to FreedomCAR—our flagship research and development initiative to reduce the nation's dependence on foreign oil and dramatically change how we power our cars and light trucks. PEM fuel cell technology is also a promising stationary power source for distributed generation, which I will also touch upon.

By way of background, the most striking feature of our transportation system is its nearly complete dependence on petroleum as an energy source. Petroleum is used to satisfy 97% of America's transportation energy needs, consuming about two-thirds of all the petroleum we use. Since roughly 55% of our petroleum is imported from abroad, the implications of this dependency on our energy security are well understood by the members of this Committee, and I need not dwell on them here.

THE "GAP" IS GROWING

This slide illustrates the expanding gap between declining domestic oil production and our increasing demand. As you can see, opening the Coastal Plain of the Arctic National Wildlife Refuge to exploration would clearly help, but that alone would not close the gap. The R&D approach we were previously embarked on would have also helped . . . but would not have closed the gap either. Indeed, both taken together would not have closed the gap.

Mindful of these realities, Secretary Abraham challenged the Department of Energy to take a bolder approach to our work. He directed us to focus our efforts on programs that "revolutionize how we approach conservation and energy efficiency." He challenged us to "leapfrog the status quo" and to pursue "dramatic environmental benefits."

In response to that challenge, we are pursuing revolutionary, transforming technologies designed to decrease our dependence on foreign petroleum. We have shifted our R&D technology portfolio to "higher risk, higher reward" strategies leading to the use of fuel cells and domestically derived hydrogen for transportation.

FREEDOMCAR IS A PARTNERSHIP

On January 9, 2002, Secretary Abraham, joined by top leadership from General Motors, Daimler Chrysler, and Ford, announced FreedomCAR at the North American International Auto Show in Detroit.

FREEDOMCAR

The CAR in FreedomCAR stands for Cooperative Automotive Research. And the "Freedom" concept represents our fundamental, long-term goals for this program:

- Freedom from petroleum dependence;
- Freedom from pollutant emissions;
- Freedom for Americans to choose the kind of vehicle they want to drive, and to drive where they want, when they want; and
- Freedom to obtain fuel affordably and conveniently.

This is a dramatic, far reaching vision . . . one that requires new technology. We cannot break the bonds of foreign oil dependency by continuing with the status quo. Given the low gasoline and diesel prices we enjoy today, we can reasonably expect consumers to continue demanding larger, heavier, more powerful vehicles, and vehicle manufacturers to continue using internal combustion engines to satisfy that demand. We clearly see this in the marketplace today. The majority of the new passenger vehicles sold in 2001 were, for the very first time in automotive history, light trucks in the form of sport utility vehicles, vans and pickups.

STRATEGIC APPROACH

If we expect to offer performance, convenience and functionality in a range of vehicles that can meet the needs of a diverse population without using petroleum, then we believe the most promising long-term approach is to employ hydrogen fuel cells combined with electric drive.

Therefore, the first element of our strategic approach is to develop technologies to enable mass production of affordable hydrogen-powered fuel cell vehicles and assure the hydrogen infrastructure to support them.

Fuel cells, of course, can be thought of as batteries that are continuously replenished by a constant supply of hydrogen. And hydrogen, the most plentiful element in the universe and the third most plentiful on earth, can be derived from a variety of sources including petroleum, natural gas, coal, biomass, and even water.

But there are significant technical and infrastructure barriers that must be overcome. Neither industry nor government, working alone, is likely to overcome these barriers in any reasonable timeframe. Therefore, we must work in partnership.

The automotive partnership that was in place in the past, the Partnership for a New Generation of Vehicles (PNGV), had some successes, and we are certainly not abandoning those successes or the collaborations it fostered. Indeed, many of the research elements of PNGV are embodied in the second element of our approach: Namely, to continue support for hybrid technologies and advanced materials that can dramatically reduce oil consumption and environmental impacts in the nearer term before fuel cells can be competitive.

One of the recognized problems of PNGV was its narrow focus on a production prototype of a family sedan. Therefore, the third element of our strategic approach is to develop technologies applicable across a wide range of passenger vehicles.

TECHNOLOGY RISKS

Yet, the technology challenges we face are daunting. To succeed, we must dramatically improve vehicle efficiency without sacrificing the performance of today's vehicles—including range, durability, start up time, acceleration, and safety.

Moreover, these technologies must be integrated in vehicles that can be manufactured in quantities of millions per year at a cost competitive with current technologies.

Since fuel cell vehicles run on hydrogen—which is not yet available at the corner gas station—elements of our technology portfolio are focused on making hydrogen production, transportation, storage, and refueling safe and affordable. We must also work toward the development of logical regulations, codes and standards governing the transportation and use of hydrogen.

In November of 2001, my office convened senior executives representing energy industries, environmental organizations and government officials to discuss the role for hydrogen systems in America's energy future. We sought a common vision for the hydrogen economy, the time frame for the vision and the key milestones needed to get there. There was general agreement that hydrogen can be America's clean energy choice, but that the transition to a hydrogen economy could well take 30 years or more to fully unfold.

TECHNOLOGY ROADMAP

We have been working on a specific technology roadmap addressing production, storage, conversion and infrastructure that leads us to that vision, and we are continuing that work as a part of the FreedomCAR program plan.

At the Global Forum on Personal Transportation on November 12, 2002 the Secretary announced the National Hydrogen Energy Roadmap. The Roadmap was developed over the last year in response to the National Energy Policy. It identifies challenges and paths forward to moving to a hydrogen economy as well as the role the government and industry will play.

The National Labs have, and will continue to play, an important role in tackling these challenges. Los Alamos and Sandia National Labs, in particular, have made significant contributions to reducing the cost of fuel cells and to developing hydrogen storage materials, respectively.

LOS ALAMOS NATIONAL LABORATORY HAS CONTRIBUTED TO REDUCING THE COST OF FUEL CELLS

Los Alamos National Laboratory has been a pioneer in the development of PEM fuel cell technology. Over the past decade, LANL has developed fuel cell stack component technology—electrodes, membrane-electrode assemblies, and fabrication processes—that have been transferred and licensed to fuel cell companies. Researchers at LANL have steadily decreased the platinum required in fuel cells—an order of magnitude reduction—which has led to a reduction in the projected cost of mass-produced fuel cell systems by an order of magnitude—from $3,000/kW ten years ago, to about $300/kW today. This cost is based on high-volume production of 500,000 fuel cell systems per year. LANL continues to work with our industry partners to improve the performance and reduce the cost of PEM fuel cells. Another order of magnitude reduction is necessary to be competitive with the cost of current internal combustion engines.

On the hydrogen side, Sandia National Laboratory has made key contributions to the development of hydrogen storage materials. Current technology relies on high pressure tanks that take up a lot of space in the fuel cell vehicle, reducing trunk space and vehicle range. We are seeking hydrogen storage systems that enable high storage capacity at low pressure.

SANDIA NATIONAL LABORATORY HAS INCREASED REVERSIBLE H_2 STORAGE CAPACITY

This slide illustrates the progress made in increasing the hydrogen storage capacity of materials developed at Sandia. We are making progress toward the DOE target of 6 weight %, triple the capacity of most existing metal hydride storage systems. But we still have a challenge ahead of us because the data are for materials only—the packaging adds weight that must be factored into the calculation. These and similar materials represent an exciting opportunity for the development of safe and efficient on-board hydrogen storage technologies that are an important enabling technology for transportation applications.

DISTRIBUTED ENERGY RESOURCES PROGRAM GOAL

We are also working to develop PEM fuel cells as a stationary, distributed power source. One of the promising opportunities for customers to manage their peak load requirements is through the use of combined heat and power systems in buildings. These systems couple natural gas fired distributed generation, such as microturbines, reciprocating engines, or fuel cells, with thermally activated cooling and humidity control equipment to meet a building's energy and indoor comfort needs. Our program goal is to build into the PEM fuel cells those characteristics that make it

a prime component as a power generator and make maximum use of recoverable energy for cooling/heating and indoor air quality for various buildings types.

BUILDING ENERGY CONSUMPTION

Exploring the use of PEM fuel cells as a means to improve overall efficiency in buildings is important since, based on statistics from the Energy Information Administration (EIA), buildings account for:

- –38% of natural gas consumption;
- –67% of generated electricity consumption; and
- –36% of national total energy consumption.

STATIONARY FUEL CELL BARRIERS

Secondly, there is significant synergy between the transportation and stationary fuel cell markets and R&D activities. For fuel cells to succeed in establishing near-term market success, our R&D must address the critical barriers associated with stationary and portable power applications. These barriers include:

- Durability. While initial performance of demonstration fuel cell systems has been very promising, operation over an extended period of time typically degrades performance of certain components such as the fuel cell membrane. Fuel cells for stationary applications must demonstrate 40,000 hours of useful life. This means that long-term testing must be carried out before the technology can be introduced into the marketplace. Introduction into a range of applications is necessary to achieve enough volume to drive down the cost of critical components.
- Higher temperature operation. To maximize the energy efficiency of fuel cell technology in stationary applications, operation at slightly higher operating temperatures is desired to allow for implementation of combined heat and power (CHP) strategies and improved heat rejection. This is a major focus of our fuel cell R&D and is an example of how we are working on technologies that simultaneously address barriers for both stationary and transportation applications.
- Fuel processing. It is anticipated that most stationary fuel cell systems will be fueled by natural gas or propane. The Department is addressing this requirement through the development of fuel processing technology that addresses issues such as cost, sulfur tolerance and improved fuel processing catalysts.

To conclude my remarks about fuel cells and FreedomCAR, we are excited about the potential of PEM fuel cell and hydrogen technologies, and we intend to remain actively engaged in partnerships with industry, academia, national labs, and other government agencies to develop and commercialize them.

Now I would like to turn to the subject of advanced lighting.

U.S. ENERGY CONSUMPTION OF ELECTRICITY, 2001

We consumed an estimated 96.3 quadrillion BTU's of primary energy in the United States in 2001, more than a third of which—or 35 quads—were used to generate electricity.

ENERGY CONSUMPTION FOR LIGHTING

A study[1] done for the Department of Energy estimates the national primary energy needed to power all the lights in U.S. homes, offices, streets and other applications at approximately 8.2 quads. In other words, lighting consumes about 22% of the total electricity used in the United States.

The lion's share of energy consumption for lighting is in the commercial sector. Moreover, commercial lighting is, by itself, a peak load component. It also contributes to a building's internal heat budget and summer air-conditioning loads—another peak load component. Therefore, in many parts of the nation we can get the additional benefit of reducing peak electricity loads if we can develop more efficient lighting.

Today, much of our lighting is relatively inefficient. My daughter once had an "Easy Bake Oven" that she used to bake cakes using an incandescent light bulb. It was a superb illustration of the fact that incandescent bulbs produce a good deal of heat as well as light—a testament to their inherent inefficiency. Incandescent light sources only produce about 15 lumens per watt.

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[1] *U.S. Lighting Market Characterization Volume I—National Lighting Inventory and Energy Consumption Estimate*, Navigant Consulting, September 2002.

Compact and tubular fluorescent light bulbs with electronic ballasts are more efficient and produce far less heat than incandescent bulbs. These light sources produce up to 90 lumens per watt.

We believe it is possible to produce higher quality lighting using advanced, solid-state technology that could deliver up to 150 lumens per watt, a 70% improvement over the best fluorescent lighting available today.

SOLID STATE INNOVATIONS

The transition to solid-state technology in lighting would mirror similar advances made in other fields. Ever since the first transistors were produced and commercialized in the late 1940s and early 50s, the inherent efficiencies of solid-state electronics have been exploited in a variety of applications. Transistors have replaced vacuum tubes in radios and consumer electronics. Solidstate screens (thin-film transistors) have replaced cathode ray tubes in computers and television sets. Today, industry is working to develop even more efficient, higher performance Organic Light Emitting Diode (OLED) displays, including miniature, ultra-high resolution, personal displays that will soon appear in a variety of consumer products.

In its simplest form, Solid State Lighting is like a photovoltaic cell running backwards—you put electrons in, and you get photons out. And you also enjoy significant advantages over conventional lighting sources such as longer life, improved efficiency, and resistance to vibration.

Solid-state devices are already penetrating selected colored light applications such as traffic signals and exit signs. These devices provide better performance and lower maintenance with 80-90% reductions in energy consumption. But there are significant cost and technical barriers to the use of this technology in the "white light" market.

My Office operates a Lighting Research and Development Program through our Building Technologies Program (BT). The mission of our Lighting R&D program is to increase efficiency in buildings by aggressively researching new lighting technologies that hold the promise of an annual savings of nearly 40% of lighting energy and $19 billion in consumer expenditures by 2020. Our program if successfully developed, works in close cooperation with industry, and last year spent over $6 million in pursuit of its mission. We look at technologies that show promise in the short, medium and long-term.

SOLID STATE LIGHTING SOURCES

Within the field of solid-state lighting, or Optoelectronics, there are three general technical subgroups, each of which can offer certain advantages for a range of applications.

- Light Emitting Diodes, or LEDs, are already competing effectively for signs and signal lighting applications, like traffic lights and pedestrian crossing signals.
- Organic Light Emitting Diodes, or OLEDs, are a flexible, organic based cousin of LEDs. Not yet achieving the same brightness as LEDs, current OLED development is focused on large displays, personal display devices and instrumentation. Our colleagues at the Defense Advanced Research Projects Agency (DARPA) routinely work with many of the manufacturers to advance ultra-high performance displays for military aviation and other defense-related applications.
- Other novel solid-state lighting, including light-producing structures such as Vertical Cavity Surface Emitting Lasers ("Vixels"), does not fit conveniently into the prior categories. We can find successful commercial examples of this technology in use today such as running the fiber-optic backbone of the Internet, and performing critical medical and scientific research.

EXAMPLES OF SOLID STATE LIGHTING APPLICATIONS TODAY

As I mentioned earlier, today's solid-state lamp can be found in many applications. You may be familiar with the NASDAQ sign in Times Square, powered by more than 18 million red, blue and green LEDs. Just like your television set, when perceived from a distance, the mix of these three primary colors produces white light—and various combinations of each can produce any color desired.

Another display technology is pictured here in the upper right hand corner. Kodak and its consortium of partners have developed a prototype OLED display that may eventually replace the computer screens and TV monitors we have today. Based on the same principle of the three primary colors—but at a far greater resolution—we find this technology starting to be used today in some mobile phones and car radio displays.

In the future, if research into this area is successful, these OLED displays could be formed into ceiling tiles and installed in our offices, being both the fixture and the light source-emitting white light or any other color we want. If the technology achieves its design objectives, it would be infinitely dimmable with no penalty in efficiency or life—thus making it a superb match for a building energy management system.

SOLID STATE LIGHTING ROADMAP

Over the past two years, DOE has been working to realize the goal of solid-state lighting. In an effort to identify the technology path we should follow to enhance and accelerate the development of white light from solid-state sources, we convened eight workshops bringing together key stakeholders from industry, academia and the national labs.

We have also sponsored a study to explore the magnitude of savings that might be possible from solid state lighting given various price performance scenarios. We will be happy to supply this to the Committee.

In conclusion, solid-state lighting potentially offers the most efficient means of converting electrons into photons. Thus far, industry has focused on signals and displays. Continued research into the uses of solid state lighting for general illumination could help us maintain technological leadership and provide us with an important tool in improving the nation's energy efficiency, identified in the President's National Energy Policy as a "national priority." We are looking at ways to accelerate this work through a stronger, better-coordinated public-private partnership.

Thank you, Mr. Chairman, for the opportunity to offer views on these important subjects. I would welcome any questions the Committee might have today or in the future.

The CHAIRMAN. Well, thank you very much.

Dr. Romig, why don't you go right ahead.

STATEMENT OF ALTON D. ROMIG, JR., VICE PRESIDENT, SCIENCE AND TECHNOLOGY AND STRATEGIC PARTNERSHIPS, SANDIA NATIONAL LABORATORIES

Dr. ROMIG. Thank you, Senator Bingaman. As Sandia's Vice President for Science and Technology and Strategic Partnerships, I'm delighted to testify today on solid-state light research and development. In the time allotted, I will highlight a few of the major points contained in my prepared written statement.

Senator Bingaman, first off, let me thank you for introducing legislation during the 107th Congress that would have authorized a next generation lighting initiative at the Department of Energy. Even though it did not become law, your bill certainly drew attention to this emerging technology and it has already stimulated programmatic support for solid-state lighting at DOE and elsewhere.

As you know, several different research consortia are already forming in preparation for a national solid-state lighting initiative. Industrial membership includes such major U.S. firms as Dupont, 3M, Kodak, Agilent, Phillips, Osram and General Electric. This initiative will be a winner for all, benefitting both businesses and the consumer, and will encourage more high-technology industrial investments here in New Mexico.

Solid-state lighting has potential for immense benefits. If most of the Nation's lighting could be converted to solid-state, we would reduce our electricity consumption by the equivalent of all the power used by all the homes in California, Oregon and Washington combined, $25 billion worth of electricity per year. It would reduce the need for power generating capacity by 17,000 megawatts, or 17 very large powerplants. And finally, it would benefit the environment by reducing the greenhouse gases that are produced by fossil fuel-based powerplants.

What is solid-state lighting? Well, here's an example. Each one of these is only one-and-a-quarter watts. Let me make sure I don't blind anybody with it. It is rather bright; only one-and-a-quarter watts apiece.

But it's technology for getting white light from a piece of semiconductor material. The goal of solid-state lighting research is to replace all of the incandescent light bulbs and fluorescent lighting tubes in the workplace and in our homes, with semiconductor light-emitting diodes, or LEDs, that produce white light.

In the past few years, a new class of semiconductor materials has been developed that make it possible to create LEDs that produce colors that were previously impossible; green, blue, violet, and most importantly again, white. And here's a small demo box, made by one of the members of our consortium, where you can see it can produce white and a variety of reds, blues, yellows, and you can do that just by simply having a different semiconductor inside each one of the envelopes to get the color that you desire.

Fluorescent white LEDs are already commercially available with an energy efficiency better than that of incandescent light bulbs in your home, which are about 5 percent, but these solid-state lighting sources are still very expensive and not yet as efficient as most fluorescents.

Our country's top semiconductor scientists, including those here at Sandia, believe that with sufficient research and development, it is possible, within 10 years, to make white LEDs that are 50 percent energy efficient. That's ten times the energy efficiency of incandescent bulbs, and far better than that of fluorescent tubes. And we also believe it will be possible to reduce the cost so that it is affordable to the consumer.

Solid-state lighting will have a huge impact on the Nation's economic competitiveness. Lighting is a $40 billion per year global industry. I fully expect that New Mexico, with its rapidly developing optoelectronics research capabilities at Sandia, Los Alamos, UNM, New Mexico State, and several industrial entities, such as EMCORE, Zia Laser, Superior MicroPowders, and others, will be a major contributor to the growth of this new technology market.

But for energy-efficient solid-state lighting to really take off, we need a national initiative, which means funding, for research and development involving Government, industry and universities in a partnership effort. We should not forget that large government-sponsored initiatives are already under way in Europe, Japan, Taiwan and Korea, and have been for up to three years, depending on which geographic region you're referring to.

Senator Bingaman, we thank you for your continued support of a national research initiative in solid-state lighting. This concludes my summary remarks, and I would be pleased to respond to any questions you might have.

[The prepared statement of Dr. Romig follows:]

PREPARED STATEMENT OF ALTON D. ROMIG, JR., VICE PRESIDENT, SCIENCE AND TECHNOLOGY PARTNERSHIPS, SANDIA NATIONAL LABORATORIES

INTRODUCTION

Mr. Chairman, thank you for the opportunity to testify today on the promise of solid-state lighting technology and the research in this area that is being conducted

at Sandia National Laboratories. I am Alton D. Romig, Jr., Vice President for Science and Technology and Strategic Partnerships, and also Chief Technology Officer, at Sandia. Sandia National Laboratories is managed and operated for the U. S. Department of Energy (DOE) by Sandia Corporation, a subsidiary of the Lockheed Martin Corporation.

Sandia is a multiprogram laboratory of DOE and one of the three National Nuclear Security Administration (NNSA) laboratories with research and development responsibility for nuclear weapons. Sandia's job is the design, development, qualification, and certification of nearly all of the non-nuclear subsystems of nuclear weapons. We perform substantial work in programs closely related to nuclear weapons, including intelligence, nonproliferation, and treaty verification technologies. As a multiprogram national laboratory, Sandia also performs research and development for DOE's energy and science offices, as well as work in national security and homeland security for other agencies when our special capabilities can make significant contributions.

I will begin my testimony with some background on solid-state lighting technology, the current state of development, and where we think the research is headed. I will then discuss the enormous beneficial impact that solid-state lighting can have on our nation's energy security, with the potential to reduce electricity consumption by 10 percent or more by 2025 over what it otherwise will be. I will also briefly describe Sandia's ongoing activities in solid-state lighting in partnership with industry. Finally, I will explain why we believe that a national initiative in solid-state lighting research and development involving government, industry, and universities will provide the best avenue for rapid development and adoption of this promising technology.

THE DEVELOPMENT OF SOLID-STATE LIGHTING

This year, about 20 percent of the United States' electricity consumption will be devoted to lighting. The vast majority of that lighting will be provided by incandescent and fluorescent bulbs, technologies that have been around for decades (or longer than a century in the case of incandescents). Incandescents are quite inefficient, with only about five or six percent of their electricity consumption being converted to visible light. The remainder is converted to waste heat, which contributes significantly to the cooling loads in buildings. Fluorescent lighting is better, but still converts only about 25 percent of the electrical energy into visible light. This wasted electricity represents an attractive target for reducing the nation's electricity bill.

Solid-state lighting, however, is a new technology which has the potential to far exceed the energy efficiencies of incandescent and fluorescent lighting. Solid-state lighting uses light-emitting diodes or "LEDs" for illumination, the same devices that provide the letters on your clock radio. The term "solid-state" refers to the fact that the light in an LED is emitted from a solid object—a block of semiconductor—rather than from a vacuum tube, as in the case of incandescents and fluorescents. (Note: I will limit my remarks to LEDs made from inorganic semiconductor materials; but it should be acknowledged that organic-based LEDs, or OLEDs, fabricated from plastic-like materials, are also expected to play a role in solid-state lighting.)

The first practical demonstration of an LED was in 1962. Since the late 1960s, the brightness of commercially available red LEDs has increased by a factor of 20 every ten years, while the cost has decreased by a factor of 10 every ten years. Early on, this rapid improvement in the technology resulted in LEDs replacing incandescent bulbs and other vacuum tubes that had previously been used for indicator lamps and numeric displays in electronics such as clock radios.

A few years ago, an innovative new semiconductor material was developed—gallium nitride (GaN)—which enabled the development of the first LEDs with bright emission in the blue and green spectral range. (Previously, bright LEDs were available only in red and orange.) This was a crucial development, since now white light could be realized by mixing different wavelength light from multiple LEDs, or alternatively by down-converting blue light to other colors of longer wavelength using phosphors.

In the past few years, the technology has progressed sufficiently that LEDs are now viable choices for single color applications such as traffic signals. Conventional 12-inch-diameter red traffic signals use a long-life, white, 140-watt incandescent bulb. The red filter over it discards 90 percent of the light, allowing only 200 lumens of the red light to pass through. A commercially available LED replacement manufactured by LumiLeds of San Jose, California, uses 18 red LEDs to provide the same amount of red light, but consumes only 14 watts. While LED traffic lights cost more than incandescents, the reduced electricity consumption allows them to pay for themselves in a year or less. They also last much longer, reducing maintenance

costs. As a result, LED-based traffic signals are becoming widely adopted throughout the country. Similarly, 90 percent of exit signs, another single-color application, are now fabricated with LEDs.

Of course, for general illumination, white light is required. LEDs must significantly improve to be economically competitive for general lighting. While today's white LEDs are more efficient than incandescent bulbs (25 lumens per watt vs. 15), they also cost as much as 100 times more per lumen. Moreover, they are not yet as efficient as fluorescent lamps (80 lumens per watt).

Solid-state lighting promises better quality and more versatile sources of lighting, including the ability to tune colors to virtually any shade or tint. Because the light can be controlled with extremely high precision, it is believed that by interfacing it with modern microelectronics, a "brave new world" of digitally controlled illumination will be achieved. Such "smart light" could even be used to interface computers into networks through the lighting fixtures themselves. In addition, solid-state lighting offers other desirable qualities, such as light weight, thinness, low heat output, flexibility in installation, lifetimes approaching ten years and longer, and extreme resistance to mechanical shock.

We believe that solid-state lighting can surpass conventional vacuum tube lighting technologies in both cost and performance within a relatively short time. With sufficient investment in research and development, it will be possible to produce a white LED with an energy efficiency of 150-200 lumens per watt, or 10 times the efficiency of incandescents and twice that of fluorescents. We expect that the cost of these highly efficient solid-state lights will be competitive, and that they can capture most of the lighting market by 2025.

THE PROMISE OF SOLID-STATE LIGHTING

What would be the impact of replacing most of the lighting in the United States with LEDs? The benefits to the nation's energy security and economic competitiveness would truly be enormous. A number of studies [1,2] find the following benefits to the United States alone (with global benefits that are proportionately larger):

- Reduction by 50 percent of electricity used for lighting
- Reduction by 10 percent of total electricity consumption
- Reduction by 17,000 megawatts of the demand for electrical generating capacity (roughly equivalent to 17 large generating plants or the residential demand from all the homes in California, Oregon, and Washington)
- Reduction in carbon emissions by the equivalent of 28 million tons per year

These large reductions in the nation's energy demands will help decrease our dependence on foreign energy sources, lessen the impact on the environment, and increase the reliability and responsiveness of the nation's electrical grid. Of course, the availability of energy is a major national security concern that has profound geopolitical implications.

In addition, it should be noted that much of the fundamental technology being developed for solid-state lighting will provide ancillary benefits to a host of other national security interests. For instance, high-power electronics can use the semiconductor material gallium nitride (GaN), which may make it possible to manufacture lighter high-power electronic devices. The new unmanned aerial vehicles now being used to great advantage by the military would benefit from lighter radars and other electronics, so that they can fly longer and farther. Even more closely related to solid-state lighting is an approach to the detection of chemical and biological warfare agents. GaN can be used to make ultraviolet LEDs and lasers. When illuminated with ultraviolet light, many biological agents will fluoresce (re-emit light at a slightly longer wavelength). We are exploring the feasibility of this technique for rapidly identifying pathogens, such as anthrax.

Finally, solid-state lighting will have an impact on our economic competitiveness, which is also a national security issue. Lighting is a $40 billion global industry, with the United States occupying roughly one-third of that market. With the higher performance and enhanced functionality that solid-state lighting offers, it is likely that the market will grow as new, unforeseen uses come into existence. I fully expect that New Mexico, with its rapidly expanding world-class optoelectronics research capabilities (including Sandia, Los Alamos, UNM, New Mexico State, and several in-

[1] M. Kendall, M. Scholand, "Energy Savings Potential of Solid-state Lighting in General Lighting Applications," U.S. Department of Energy, Washington, DC (April 2001).

[2] T. Drennan, R. Haitz, J. Tsao, "A Market Diffusion and Energy Impact Model for Solid-state Lighting," presented at the 21st Annual North American Conference of the U.S. Association of Energy Economics and International Association for Energy Economics, Philadelphia, September 2000.

dustrial entities such as EMCORE, Zia Laser, Superior Micropowders, and others) will contribute to the growth of this new technology market.

Europe, Japan, Taiwan, and Korea have all established large government-sponsored industrial research consortia to further develop solid-state lighting technologies. It is possible that without a substantial government/industry commitment in the United States, foreign competitors will come to dominate solid-state lighting. For all the reasons outlined above, this development would result in an unfavorable impact on our national security position.

SANDIA'S RESEARCH ACTIVITIES IN SOLID-STATE LIGHTING

Sandia has a long history of research in semiconductor optoelectronic devices. Indeed, we were pioneers in the technology of the vertical cavity surface emitting laser, or VCSEL, which is now a mainstay of the telecommunications industry.

A few years ago we began to realize the tremendous possibilities presented by harnessing semiconductor technology for lighting. Sandia, working with leading industrial scientists from Agilent, wrote some of the first papers on solid-state lighting.[3,4] In 2000, we helped the Department of Energy and the Optoelectronics Industrial Development Association (OIDA) organize a national Solid-State Lighting Technology Roadmapping Workshop in Albuquerque. That workshop identified the major scientific and technological challenges to be overcome and established technology milestones for future years. A follow-up workshop, also in Albuquerque and partially organized by Sandia, was held in May and updated the challenges and milestones. Copies of the Roadmap Reports from both of these workshops are available from OIDA.[5,6]

In the past couple of years, Sandia has also harnessed its optoelectronics expertise to perform internal research on solid-state lighting. Under the Laboratory-Directed Research and Development (LDRD) program, we are currently pursuing a Grand Challenge project devoted entirely to solid-state lighting. In fiscal year 2001, we invested $1.3 million in this project; in 2002 we are investing $2.3 million; and in 2003 we anticipate increasing our investment again. At present, approximately 25 investigators are involved in the project, either full or part-time. Our research seeks to overcome the technical challenges identified in the OIDA technology roadmaps. It focuses on the physics of defects and impurities in nitride-based semiconductors, growth of high-quality, low-cost, nitride semiconductor material, design of high-efficiency LEDs, development of phosphors for white light, and encapsulants and packaging to give the LEDs long lifetimes. We are collaborating in these research areas with several universities and industrial partners.

THE NEED FOR A GOVERNMENT/INDUSTRY PARTNERSHIP

While numerous university, industry, and national laboratories are engaging in various aspects of solid-state lighting research, there is a general consensus that a government-sponsored national initiative is needed to make solid-state lighting a reality within a reasonable time. Such an initiative would involve a consortium of U.S. industries in partnership with universities and national laboratories. There are four reasons why such a partnership is desirable:

1. Basic research in high-risk areas cannot easily be pursued by industry alone, particularly in today's tough business environment. This type of work provides understanding of the underlying physics. Industry can rarely afford to devote personnel and equipment for this high-risk, long-term activity. Industry agrees that this type of pre-competitive research will be essential for overcoming some of the challenges we face, and several industrial firms have committed to substantial cost-sharing in a national initiative, both in-kind and with cash, for this research.
2. A national initiative will provide a unifying focus for the entire effort, enabling research to be coordinated and tasks efficiently assigned. This will help ensure that the fundamental research performed at universities and national

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[3] R. Haitz, F. Kish, J. Tsao, J. Nelson, "The Case for a National Research Program on Semiconductor Lighting" (1999). Hewlett-Packard/Sandia National Laboratories white paper. Copies are available from Sandia National Laboratories through the Internet at http://lighting.sandia.gov, and from the Optoelectronic Industry Development Association, 1133 Connecticut Ave. NW, Suite 600, Washington, DC 20036-4380.

[4] R. Haitz, F. Kish, J. Tsao, J. Nelson, "Another Semiconductor Revolution: This Time It's Lighting!" Compound Semiconductor Magazine, Volume 6, No. 2 (March 2000).

[5] *Light Emitting Diodes (LEDs) for General Illumination: An OIDA Technology Roadmap*, Eric D. Jones, ed., Optoelectronic Industry Development Association (2001).

[6] *Light Emitting Diodes (LEDs) for General Illumination II: An OIDA Technology Roadmap*, Jeff Y. Tsao, ed., Optoelectronic Industry Development Association, in press.

labs focuses on the most relevant and promising areas, and that industry remains abreast of recent developments and is able to incorporate them in products rapidly.

3. A national government/industry partnership will help to develop an infrastructure of suppliers and equipment firms to support the commercialization of this new technology.

4. Finally, a national initiative in solid-state lighting research will provide a long-term funding structure and resources necessary to develop this new technology. While solid-state lighting might become a reality without federal investment, a government program would accelerate the process by one or two decades.

Studies [1,2] indicate that with an investment of approximately $50 million per year, solid-state lighting technology could be substantially achieved within ten years. The accelerated introduction of solid-state lighting would pay for itself many times over in reduced electricity charges to rate-payers alone. I have already mentioned the economic benefits that could be lost if we yield leadership in this field to other countries, which have ongoing government programs.

The Next Generation Lighting Initiative Act introduced last year by Senator Bingaman and Senator Dewine proposes just such a government/industry partnership. An industrial consortium, coordinated by the Optoelectronics Industrial Development Association (OIDA) has already been formed in preparation for enactment of this Initiative. Members include major firms such as Dupont, 3M, Kodak, Agilent, Philips, Osram, Corning, Siemens, and of course, General Electric. The Next Generation Lighting Initiative has many similarities with SEMATECH, the government-sponsored research and development consortium that began in the middle 1980s and helped develop high-tech process equipment for our semiconductor industry. We envision a second semiconductor revolution this time in lighting.

SUMMARY AND CONCLUSION

The technology of solid-state lighting is destined to change our lives. Early maturation of this technology would lead to enormous benefits for the nation and indeed the world. Economic, environmental, and national security advantages will be realized, not only by the general reduction in total electricity consumption, but also through spin-off technologies emerging from the underlying semiconductor sciences.

Although Sandia and other institutions in government, industry, and the academic sector are working hard on solid-state lighting, a national initiative based on a government/industry partnership would greatly accelerate the research and development process. This initiative will coordinate independent research efforts toward a common goal and will enable solid-state lighting to become commercially viable one or two decades earlier than might otherwise happen.

Mr. Chairman, I would like to thank you for your vision and leadership in introducing legislation to make the Next Generation Lighting Initiative a reality. Sandia supports the Next Generation Lighting Initiative Act wholeheartedly, and we would like to offer our expertise in this national endeavor. We believe that the Next Generation Lighting Initiative will be a winner for all, benefiting both businesses and the consumer, both New Mexico and the nation, and indeed, humanity at large.

The CHAIRMAN. Well, thank you very much.

Dr. Becker, why don't you go ahead and give us General Electric's perspective on all this.

STATEMENT OF CHARLES A. BECKER, Ph.D., MANAGER, LEDS FOR LIGHTING, GE GLOBAL RESEARCH, GELCORE, LLC

Dr. BECKER. Okay.

Senator Bingaman, I would like to thank you for the opportunity to testify today on behalf of the Next Generation Lighting Initiative. I am the project manager for advanced LED research at GE's Global Research Center in Schenectady, New York, and I am also the former vice president of Technology for GELcore LLC, which is located in Valley View, Ohio.

GELcore is a joint venture between GE's lighting business and EMCORE. EMCORE has operations both here in New Mexico and in Somerset, New Jersey. GELcore is one of the world's largest sup-

pliers of energy-saving LED-based systems with products today in traffic signals, signage and automotive applications.

Mr. Moorer and Dr. Romig have amply described the energy savings opportunity of solid-state lighting as is envisioned in the Next Generation Lighting Initiative and have described, somewhat, about the exciting inorganic light-emitting technology, which would be critical to this revolution over the next decade. My written testimony is entirely consistent with these observations and elaborates on several examples.

I mention here only one example to emphasize that energy savings are already being attained through LED technology. GELcore annually produces hundreds of thousands of LED traffic signals, which consume less than one-tenth of the energy used by traditional signals and last more than ten times as long. The energy savings from the GELcore signals installed last year alone will total over 150 million kilowatt hours each year, for years to come. That's enough energy to light about 17,000 homes.

GE and GELcore, investing heavily in solid-state lighting, believe it's crucial technology for global competitiveness. It's also a technology which is evolving extremely rapidly. Two-and-a-half years ago, the brightest white LED you could obtain commercially was a 2-lumen LED suitable for key chains and, basically, toys.

A year-and-a-half ago, the industry introduced 25- to 30-lumen LEDs, as Dr. Romig showed the board here, and earlier this year, 120-lumen LEDs were introduced. This factor of 60 in 2½ years is an extremely rapid rate of progress, and it demonstrates how quickly this technology is evolving and has the potential to evolve going forward.

I'll focus the remainder of my remarks on a very brief discussion on the promise of organic light-emitting diode technology, and then offer GE's perspective on the importance of the consortium structure and Government support for NGLI.

Like inorganic LEDs described earlier, organic LEDs produce light directly from the energy transition of electrons inside solid materials. The difference is that the semiconductors in OLEDs are specialized plastics in sheet form. The state-of-the-art of white OLED devices is several years behind that of LED devices, but is also progressing rapidly.

GE Global Research, aided by Department of Energy funding, has produced the first white illumination-quality OLED devices in the past year. These devices now emit the same amount of light per unit area as typical fluorescent fixtures; however, the most advanced of these devices are still only six-by-six inches square. They produce about 70 lumens, and they have an efficiency of about half that of incandescent lamps.

We see no fundamental physical reasons why, with development, this performance cannot equal that of inorganic LEDs and surpass that of traditional fluorescents and other light sources.

The exciting draw for OLED technology as a compliment to inorganic LEDs is the potential for very low cost. We believe that these plastics can be manufactured at very high volumes in roll-to-roll machines that resemble printing presses, much like newspapers. They're inherently flat in nature, which makes them ideal for room

illumination. With sufficient investment, we see OLEDs and LEDs as complimentary long-term solid-state lighting components.

Mr. Chairman, GELcore and GE view increased government support of solid-state lighting as a critical element in our global technology competitiveness. We've been strong supporters of what is now called the Next Generation Lighting Initiative since it was first proposed by the Sandia and Hewlett-Packard white paper in early 2000. Thanks to your leadership in introducing the next generation lighting bill, this vision has become a reality with significant momentum and broad industry support over the past year-and-a-half.

GE and GELcore are both charter members in the next generation lighting consortia. Working with the Department of Energy, other major lighting companies, national labs and universities, we have helped create detailed technical roadmaps for both LED and OLED technologies as described by Mr. Moorer.

We believe that the most effective way to achieve the many technical breakthroughs needed to make solid-state lighting practical and affordable is by close industry development and Department of Energy cooperation and investment in basic research starting as quickly as possible.

As stated by Dr. Romig, significant Government investment is already in place around the world, trying to capture the critical enabling technologies for light sources of the future.

Thank you for your continued support of the Next Generation Lighting Initiative and for giving me an opportunity to speak here today. I'd be happy to respond to any questions that you might have.

[The prepared statement of Dr. Becker follows:]

PREPARED STATEMENT OF CHARLES A. BECKER, PH.D., MANAGER, LEDS FOR LIGHTING, GE GLOBAL RESEARCH, GELCORE, LLC

INTRODUCTION

Mr. Chairman, I appreciate the opportunity to testify today on a very important initiative for energy efficiency, the Next Generation Lighting Initiative (NGLI). NGLI, which is authorized in pending House and Senate energy legislation, brings together government, industry, national laboratories, and academia to develop a new form of energy-efficient lighting based on solid state light sources. It is a part of the Lighting Research and Development budget of the Department of Energy's Office of Building Technology, State and Community programs.

Despite an on-going U.S. industry and government investment and commitment to the development of energy-saving solid state lighting, substantial technical obstacles remain. Full scale commercial deployment will be significantly delayed, or achieved first by foreign competitors, unless an effective and coordinated U.S. government and industry research and development effort is launched. The objective of NGLI, which is built around a 10-year program within the Department of Energy and a consortium led by the solid state lighting industry, is to accelerate the US-based research and development necessary for transforming solid state lighting into a primary source for the nation's and the world's general lighting needs.

In anticipation of NGLI, several leading optoelectronics and lighting companies—including General Electric, GELcore, Emcore, Philips, Agilent, LumiLeds, Osram, 3M, Corning, and Cree—have already joined in a solid state lighting consortium, coordinated by the Optoelectronics Industry Development Association (OIDA). In addition to this industry support, NGLI has support from the Department of Energy. Both the Office of Energy Efficiency/Renewable energy, represented here by Secretary Garman, and Sandia National Lab, represented by Dr. Romig, have played critical roles in shaping the technical program to ensure success. Mr. Chairman, you and Senator DeWine introduced the original legislation for Next Generation Lighting in the spring of 2001. Since that time, many Members of Congress have strongly

endorsed the initiative. In fact, 22 members of the Senate and 22 members of the House of Representatives wrote letters to endorse funding for NGLI in fiscal year 2003. The Secretary of Energy this summer used solid state lighting as an example of an initiative that could have high impact on energy efficiency.

This strong show of government interest, as well as the technology road mapping activities sponsored by OIDA and the DOE, have already created tremendous momentum in the community towards achieving the goals of NGLI, and have aroused the interest of numerous leading U.S. universities, who are anxious to focus their research in this area.

General Electric has a longstanding commitment to energy efficient lighting, as evidenced by several successful programs in conventional lighting with the Department of Energy's Office of Building Technology. In 1999, GE Lighting teamed with Emcore, a leading manufacturer of wide bandgap semiconductor equipment and devices, to form the GELcore joint venture, with a clear charter to forge the way in solid state lighting. To accomplish this task, GELcore draws on the technology strengths of GE Lighting, GE Global Research, and Emcore, as well as the global market access and application knowledge of GE Lighting.

While investing heavily in the advanced technology required to enable white solid state lighting in the future, GELcore is already helping to reduce energy consumption through Light Emitting Diode (LED) applications. We are one of the largest North American manufacturers of LED traffic signals, which reduce electricity usage by up to 90% in hundreds of thousands of installations across the country. GELcore traffic signals sold in the U.S. over the last year will save more than 150 million kilowatt hours of electricity every year for many years to come! GELcore has also recently introduced Tetra™, a new LED system that replaces the neon tubes currently used in channel letter signs on commercial buildings, again reducing the energy used by 80% or more.

Finally, GE Lighting and GE Global Research, with Department of Energy help, are also investing in Organic Light Emitting Diode (OLED) white light technology. While this technology is several years less mature and more risky than inorganic light emitting diodes, it holds the promise of very low costs for large area lighting panels, as I will explain later.

THE NEED FOR MORE ENERGY EFFICIENT LIGHTING

Lighting consumes a large and growing portion of all energy generated in the United States—currently over 20 percent. Improvements in lighting must be a primary focus to limit future growth in energy consumption.

The incandescent light bulb and the fluorescent light tube have long been the primary sources for general lighting needs. As very mature technologies, these light sources have achieved only incremental improvements over the last decades, and are near their maximum potential energy efficiencies. Both convert only a small portion of the energy they consume into visible light. A 100-watt incandescent light bulb, for example, generates light from a glowing hot filament, emitting only 5 percent of the energy it consumes as useful light, and the rest as heat. Fluorescent tubes generate light by converting an ultraviolet discharge from mercury gas to white light, but still convert less than 30% of their electrical consumption into usable light, the remainder ending up as waste heat. These inefficiencies are the result of fundamental physics and are not subject to significant improvements.

Solid State Lighting is based on the generation of light by inorganic or organic semiconductor light emitting diodes. LEDs and OLEDs are new technologies for light generation, and are governed by different physical principles than conventional lighting. These technologies today can convert over 50% of their electrical energy into usable light in limited cases, and have the potential to approach 100% conversion if certain technical barriers are overcome. The goal of the NGLI program is to develop practical, affordable white lamps with more than twice the efficiency of today's fluorescent lamps.

SOLID STATE LIGHTING: THE TECHNOLOGY AND ITS BENEFITS

Solid state lighting technology utilizes semiconductor devices known as light emitting diodes or organic light emitting diodes to generate light directly from the energy transitions of electrons in semiconductor structures. Like solid state integrated circuits, these devices are potentially highly energy efficient, long lasting, and robust. In addition, like integrated circuits, their cost of manufacture can be reduced exponentially year after year, as the technology matures and volumes increase. By comparison, traditional light bulbs are like the vacuum tubes of more than 30 years ago—short lived, mechanically fragile, expensive, and hot. In addition, lighting devices based on LEDs and OLEDs will offer a variety of new consumer advantages,

including extremely long lives, highly directional lighting, reduced “light pollution,” a wide choice of colors, and easy brightness adjustment.

LEDs

General Electric scientists actually invented the first inorganic LEDs 40 years ago, but the brightness levels and available colors were such that, until fairly recently, these devices have been useful only as indicator or panel lights, such as those on electronic equipment. Over the last decade, continuous improvements in LED lamp efficiency, and the discovery of new semiconductor systems that allow all visible colors to be efficiently generated, have made it possible to produce LEDs that can actually throw usable light for illuminating other objects. It has been practical since the mid nineties to use LEDs in applications such as traffic lights, highway and exit signs, large area video displays, and certain automotive lighting. However, in order to achieve mass market acceptance of solid state lighting, particularly as a source for general lighting needs, we still need to improve efficiencies by nearly a factor of ten, reduce costs by a factor of more than 100, improve the color characteristics, and create the standards and infrastructure to allow easy use and interchangeability among brands and fixtures. Once these obstacles are overcome, the full-scale deployment of solid state lighting technology offers the potential for the substantial economic, environmental, consumer, and other benefits outlined by Secretary Garman and Dr. Romig.

A typical white LED lamp is a system that consists of one or more semiconductor chips, a phosphor for converting the single color emission of the chip into white light, and a package which holds and protects the chip and phosphor, removes waste heat, and shapes the light output. Reaching the efficiency and cost levels envisioned by NGLI will require significant improvement in all of these components and in the optimization of the entire system.

As just one example of dozens of technologies which need improvement, we can consider the growth of the light emitting semiconductor that is fashioned into an LED chip. Current state of the art production for blue LEDs requires the growth of what is called a wide bandgap semiconductor material on specialized, expensive wafers made of either sapphire or silicon carbide. Multi million dollar machines are used to grow this semiconductor layer one atomic layer at a time in a several hour process on 2 or 3 inch diameter wafers. Although a single wafer can produce over ten thousand small LED chips, current yields can be as low 50%. As the experience of the silicon chip industry over the last half of the 20th century shows, larger wafer diameters, better starting materials, more efficient growth machines, and traditional yield improvement techniques can dramatically reduce the finished cost of chip, while simultaneously improving performance. The NGLI roadmap calls for the industry to “stand on the shoulders” of the silicon chip industry, forging new technologies only where they are required by the unique problems of generating light rather than logic from chips.

OLEDS

Organic LEDs, or OLEDS, also produce light directly from the energy transitions of electrons, but do so in specialized organic materials, rather than in crystalline inorganic semiconductors. These light emitting organic materials are placed between electrical contacts on large area glass or plastic sheets, and emit light when current is passed through them. Since the processing of such sheets can be done in large machines like printing presses, rather than in typical semiconductor equipment, OLEDS can potentially be made extremely inexpensively.

The state of the art in white OLEDS is years behind that in LED systems, but is rapidly improving, with the efficiencies of some colors increasing by over 100 fold in less than 10 years. Substantial challenges for this technology remain in overall efficiency, lifetime, and the demonstration of the expected low cost manufacturing methods. New light emitting materials, sealing techniques, and high speed manufacturing processes are all required. An adjacent industry, which is synergistic to this technology, is the development of large area, organic material based photovoltaic cells.

Infrastructure

To realize the full savings potential of solid state lighting, the industry must also develop and adopt a number of “system” standards, making LED or OLED based light sources as practical and easy to use as today’s common incandescent or fluorescent lamps. The technical roadmaps created by the industry with DoE involvement also address these areas. As an example, new, highly efficient power supplies and control systems and technologies will be needed to provide the voltages required by LED and OLED systems. In addition, since we have far more control over the color

and placement of light with solid state sources, human factors studies will be needed to optimize lighting for the working and living environments.

Impact

It is estimated that, given expected market penetration, solid state lighting could reduce global electricity usage for lighting by 50 percent over the next twenty years and reduce total global electricity consumption by 10 percent. These changes equate to an overall reduction in annual global energy needs of 1,000 terawatt-hours representing an annual saving of over 100 billion dollars. The energy efficiency of these devices will also translate into major reductions in carbon emissions. It has been estimated that the United States alone could avoid over 200 million metric tons of cumulative carbon emissions by 2020 if solid state lighting garners a significant share of the general lighting market.

Solid state lighting promises better quality and more versatile sources of lighting, including the ability to tune colors to virtually any shade or tint. It also offers other desirable qualities, such as light weight, small size, flexibility in deployment, and compatibility with integrated circuits to produce "smart" light.

Finally, solid state lighting will be far more cost efficient in terms of product maintenance and replacement. Unlike incandescent bulbs and fluorescent tubes, LEDs and OLEDs are durable, long lasting, and easier to operate and control. An example is this LED based stoplight, which can be guaranteed for at least five year operation, and replaces incandescent lamps requiring replacement as often as twice per year. In some architectural applications, the very long life of LEDs may even make it possible to incorporate them as a permanent part of the structure, significantly reducing overall costs and building maintenance.

Moreover, a flourishing solid state lighting industry will have other important economic benefits to the United States in terms of employment, growth in supplier and equipment industries, research and development and new applications. As Dr. Romig points out, there are also substantial potential benefits to the general wide bandgap semiconductor industry, with multiple industrial and national defense applications. Furthermore, as solid state lighting becomes a leading source for general lighting outside the United States, the U.S. solid state lighting and related industries will reap expanded economic benefits for the nation.

THE NEED FOR A GOVERNMENT-INDUSTRY INITIATIVE

Based on the benefits of solid state lighting, including the need to reduce energy consumption related to lighting, a government-industry initiative to develop and mass market this technology will be in the United States' economic and energy security interests. The United States will benefit not only from major energy and cost savings, improved lighting quality, and a positive environmental impact, but also from the ability to enhance and maintain the competitiveness of the U.S. solid state lighting industry at a time when this technology is being aggressively pursued by other nations.

Efforts are underway in other countries to rapidly develop solid state lighting as a viable alternative to conventional lighting technologies. Government-sponsored industry consortia have been established in Japan, Korea, and Taiwan to develop more efficient solid state lighting technologies. It is generally believed that without a substantial government-industry commitment in the United States, competitors such as Japan and Taiwan will come to dominate solid state lighting and become the standard-bearers of this important technology.

Current technology roadmaps for solid state lighting indicate that the cost reductions and product development work necessary to commercialize this technology for the general lighting market could take a minimum of 12-18 years. The implementation of a focused government-industry initiative to further develop this technology for general illumination will substantially reduce this timeframe. Such a shared initiative would reduce the cost of research and development, enable important information sharing, and accelerate technology innovation and the development of domestic and international standards.

The companies which have formed the solid state lighting consortium will continue to invest heavily in this technology, even in the absence of NGLI.. However, there are clearly major advantages that will accrue from the forming and funding of NGLI.

First, such a coordinated program will significantly accelerate the development of key underlying technologies by providing both industry and government funding and sharing of critical pre-competitive high risk technologies which no one company can afford.

Second, the communication forum and mutual trust that such an arrangement between industry and the DOE provides will allow faster progress by all companies

involved and the industry as a whole. The SEMATECH consortium formed in the 1980's is an outstanding model for the potential of such research cooperation and scientific collaboration between major industry players, their suppliers, end users, universities, national labs, and the government to meet and outperform global competition.

Finally, by involving not only the large lighting companies, but also the equipment, packaging, fixture, architectural, and other infrastructure companies in the lighting industry, this initiative will speed the practical market acceptance of solid state lighting. The most efficient lighting technology in the world will not save energy unless it is practical, easy, and cost efficient to install.

The CHAIRMAN. Well, thank you, all three, for excellent testimony.

Let me start by asking you, Mr. Moorer, if you had a chance to review the proposal that we did introduce in this last Congress to establish a next generation lighting initiative and essentially commit substantially increased level of Federal support to work with industry to develop this technology. Have you reviewed that? Do you have a position on that, or any thoughts on the appropriateness and value of that?

Mr. MOORER. Yes, sir, Mr. Chairman. I have not reviewed it in its entirety, but I am familiar with it. I don't have a position on it, but I would like to make the comment that we are always looking for opportunities to develop public-private partnerships, and we always try and make sure that we can make a case that there is a need for a Federal role in developing technology.

We try to make sure that we can define a very clear strategy for such a partnership, that we have measurable goals, and that we are always evaluating the progress of that partnership against what is really the changing marketplace, and that's something that we look to industry to do.

In our own program, we continue to look for ways to increase the amount of emphasis that we're putting on solid-state lighting, and I think I would leave it at that.

The CHAIRMAN. Let me just ask, you know, one of the analogies that has been referred to by many is what the Federal Government did with the semiconductor industry, when it initially provided funding, for several years, for the SEMATECH operation, which established itself down in Austin, Texas. That was a circumstance where the Reagan administration stepped up and committed Federal funds through the Department of Defense. Secretary Weinberger supported that initiative as Secretary of Defense, and the result that—at least as I have understood the history, and some of you on the panel probably could correct me on this, but the result was that the U.S. firms in the semiconductor business were able to retain and capture a substantially larger portion of the employment and market and have maintained it through today, as we can see with Intel's operation across the river here.

Is that—is an analogy between where we are today in solid-state lighting and where the semiconductor industry was back in the early 1980's or mid-1980's with semiconductors, is that a reasonable analogy, Mr. Moorer, or not?

Mr. MOORER. I think it is a fairly reasonable analogy, and I think that we've really stepped up the amount of work that we've done just in the last year-and-a-half with respect to the workshops that I mentioned in my testimony, to try to get together with the

industry and with the national laboratories to actually try and see what we can develop.

The CHAIRMAN. Let me ask, Dr. Becker, you referred, and also Dr. Romig referred, to these efforts that are being made in some other countries. I think you mentioned Europe, Japan, Taiwan and Korea.

Dr. BECKER. Yes.

The CHAIRMAN. What is the extent of those efforts? Are they essentially what we're doing, the development of roadmaps, workshops, or is there real long-term commitment funding? What is happening in these areas?

Dr. BECKER. I'll speak about the Japanese commitment, which I believe is currently 5 years, approximately $50 million per year of government subsidy. We've heard recently that there's a move afoot underneath this initiative to actually increase and lengthen that initiative within Japan. It's called the 21st Century Lighting Initiative. It consists of the major Japanese lighting companies, as well as several of the semiconductor companies. It is focusing on developing ultraviolet-based white LEDs. These would be LEDs that might have—well, mostly have an advantage in terms of the quality of color.

As you know, the adoption of some lighting technologies, such as compact fluorescents, has been fairly slow because people dislike the color, dislike the long warm-up time. We believe that LEDs, if we're not careful, may suffer the same fate, so we're working very hard to understand the quality of light that's required, and the Japanese initiative seems to be focused on that.

A more recent initiative is starting up in Taiwan, which has installed an incredible capacity over the last few years. This is the type of reactors needed for LED technology and has begun to enter the white LED market at the low end, but has set its sights very high.

The CHAIRMAN. Dr. Romig, did you have any information you could give us on these other efforts that are going on internationally?

Dr. ROMIG. I think the one place where I would add a comment is the European effort is more recent than the Japanese. They're in their second year, but their strategy is very much the same around roadmapping, equipment, producing of products, and it has a level of funding that is, in fact, on that same order of magnitude, around 50 million U.S. dollars per year.

I'd also to like add a comment about your SEMATECH. Having been involved in that program, I do see one difference in this initiative and SEMATECH: it's one where individuals such as yourself will be so vitally important. In the case of semiconductors, we, of course, were the world leaders, and we lost that leadership position, and we all know that Americans are very good at reacting to things, and so we reacted to that loss of leadership underneath a potential threat to our national security.

This is a case where it's a new ball game, and it's not a matter of getting back into it, and so you can't quite ring the alarm bells the same as you could around semiconductors, and so although the business model is a very good analogy, the political courage to

drive this one forward will be a little more challenging, I think, than SEMATECH was.

The CHAIRMAN. Is there a funding available today to assist with these technologies, Mr. Moorer, and how does it compare to the 50 million a year that Dr. Becker referred to in Japan?

Mr. MOORER. We are spending about 4 million a year right now in this area on a program that's totally directed at this. We have some other programs that are targeted at small businesses and universities where we try to take some of our high-priority areas of research and get some funding done there, so if you were to add those projects, as well, it approaches about $6 million a year in support right now.

The CHAIRMAN. Do you know if there's a plan in the upcoming budget submission to the Congress to increase that?

Mr. MOORER. I probably shouldn't comment on that, Mr. Chairman, at this point.

The CHAIRMAN. Okay. That's still in the works.

Mr. MOORER. Yes, sir.

The CHAIRMAN. Okay. Let me ask another—since you're only testifying on this first panel, Mr. Moorer, you did testify both about the solid-state lighting and the fuel cell technology. One concern that I've got, and I think some of the witnesses on the second panel will bring this out, but since you won't be back up here as a witness, let me ask you about it.

Ned Godshall, the CEO of MesoFuel, he has in his testimony here a statement that I think is interesting. He says, "Government investment in hydrogen generation and hydrocarbon reforming will have a far bigger impact on fuel cell adoption rates than additional funds applied to either fuel cells or cars."

Now, the effort that the administration has made to date with the FreedomCAR, that being, as you've pointed out, the flagship project to move us into a hydrogen economy, hydrogen-based economy, would seem to assume something else, would seem to disagree with what Dr. Godshall—or Ned Godshall—is saying here. What is your response to that?

Mr. MOORER. Well, I think if we strictly look at the dollars being invested being his point, and I hate to try to speculate on his comment, we are spending within the Office of Energy Efficiency and Renewable Energy about $2 to 1 for fuel cell and propulsion technology versus hydrogen production, if I think that's where he's coming from.

However, if you look at the entire Department of Energy, and look at all of the work that we have going on right now, there is a fair amount of work that you might define as indirectly supportive of hydrogen production. If you look at the fossil program and the work that's being done there on gasification and those sorts of technologies, there is a fair amount of work that would be considered indirectly supportive of the production of hydrogen.

I think I should point out that there are a couple things that have happened that are trying to make sure that we, in fact, do have a balanced program. One is the hydrogen roadmap that I mentioned in my testimony.

We're also, right now, involved in producing a hydrogen posture plan which continues to follow through on making sure that we

have a balanced program with respect to both, not just the production and the use of that hydrogen, but also how do we move it? How do we store it? So there are a whole host of issues in trying to drive home the hydrogen economy.

The CHAIRMAN. Did you say you have something else that's coming out in addition to the hydrogen—so-called hydrogen roadmap that you've already issued?

What is that that's coming out?

Mr. MOORER. It's a so-called posture plan, the Under Secretary has asked us for, which is something that we're doing in connection with that roadmap.

The CHAIRMAN. And who is developing this posture plan?

Mr. MOORER. It's an effort to, you know, there's always this challenge of trying to coordinate activities across various elements of not just a single department, but various governmental agencies, as well as trying to get a handle on what's happening in the industry, and what we're trying to do here is basically follow through on the hydrogen roadmap, which asked us to try to bring together all of the elements within the Department of Energy that are working on fuel cell technology and the fuels that would power those fuel cells.

The CHAIRMAN. But this posture plan is being developed internally within the department; it's not an outside group.

Mr. MOORER. That's correct. That's correct.

The CHAIRMAN. Okay. All right. Well, thank you. I think this is useful testimony, and obviously, we'll have a chance to get into some of the hydrogen and fuel cell issues in more depth here with the second panel.

Let me just thank all the witnesses, and particularly thank Dr. Becker and Dr. Romig for your support of this next generation lighting effort. We will continue to push that in the new Congress, and we hope very much we can persuade the Department of Energy to support that. I think it would be a very good thing and might actually create some jobs, which would be a good thing.

Mr. MOORER. Mr. Chairman, if I may?

The CHAIRMAN. Yes.

Mr. MOORER. You asked me, before the hearing started, about the juxtaposition of these two topics at today's hearing, and it strikes me that there are some major common issues that face both these exciting areas.

One is this issue of U.S. superiority or U.S. leadership in both these areas. We're seeing foreign investment, foreign government support, both in solid-state lighting and in fuel cell technology, rapidly growing. We have the need for public-private partnerships, trying to make sure that the Government is working in an appropriate way with the private sector, and then, finally, recognizing the value of our national laboratories. I believe both these areas can benefit from that. Thank you.

The CHAIRMAN. All right. Thank you all very much. Why don't we go ahead with the second panel, Dr. Stroh with Los Alamos National Laboratory; Dr. Mark Hampden-Smith, and Dr. Ned Godshall.

Okay. I already went through a very short introduction of each of you. Why don't we just—if no one has any particular preference

on this, Dr. Stroh, why don't you start, and we'll just come right down the table here and hear from each of you, and then I'll have a few questions. Go right ahead.

STATEMENT OF DR. KENNETH R. STROH, MATERIALS SCIENCE AND TECHNOLOGY DIVISION, LOS ALAMOS NATIONAL LABORATORY

Dr. STROH. Thank you, Mr. Chairman, for the opportunity to report this morning on the status of our hydrogen and fuel cell programs at Los Alamos National Laboratory. I'm Ken Stroh, and I've worked at Los Alamos for nearly 25 years on energy systems design, analysis and testing, but for the last 10 years, my focus has been on fuel cells, and I currently manage the lab-wide efforts on hydrogen, fuel cells and vehicle technologies at Los Alamos. I expand on the brief comments I'm going to make here this morning in my written testimony.

Since 1977, the laboratory has been performing leading-edge research on polymer electrolyte membrane, or PEM, fuel cells and the supporting technologies, with our primary funding coming from the U.S. Department of Energy. Fuel cells directly convert the chemical energy in a fuel to electricity with higher efficiency and reduced environmental impacts compared to fuel combustion and energy conversion in conventional engines or turbines.

These highly efficient power conversion systems are fueled by hydrogen and have emissions of greenhouse gases and criteria pollutants that can approach zero when the hydrogen is made from a clean process. Hydrogen can be derived from an array of diverse domestic energy sources, thereby adding to our energy security.

Systems coupling hydrogen production from water via electrolysis, together with hydrogen storage and fuel cells, if such systems can be made economical and durable, would enable intermittent renewable energy sources, such as the sun and the wind, to drive systems that dispatch power on demand. Such systems could be ideal for off-grid power in remote locations or as part of a distributed power system and would be emission-free and, more importantly, sustainable.

The hydrogen and fuel cells program in Los Alamos has helped advance these technologies to the point where they can be considered for broad application to our power needs; for applications that range from cell phones, laptop computers and portable electronics, to combined heat and power for residential, commercial and industrial buildings, to transportation.

The focus of the Los Alamos effort over many years has been on pre-competitive fundamental research that thereby enables knowledge-based innovation. Deputy Assistant Secretary Moorer mentioned one such area in the reduction of the amount of platinum catalyst required, an enabling breakthrough for the industry. Our goal is to further reduce or even eliminate the need for this expensive and limited commodity.

Collaboration with industry has been a characteristic of the Los Alamos program from the earliest days. In a recent letter to the Department of Energy, the co-director of General Motors Global Alternative Propulsion Center stated, "Collaboration with Los Alamos, supported by the Department of Energy, serves as the tech-

nical foundation for the intensive development effort in fuel cells at General Motors today."

Many key players in the emerging domestic fuel cell industry trained or worked in the Los Alamos program. And many of the first tests of pre-commercial products developed by these companies were performed at the laboratory.

Although the promise of a sustainable clean energy future based on renewable hydrogen and fuel cells is compelling, many technical barriers remain to realizing that vision. State-of-the-art fuel cells are still too expensive, even when one considers the cost savings of mass production, and they are still too large, too heavy, too fragile for widespread application. Hydrogen generation and storage present additional challenges.

The continuing contraction of the fledgling fuel cell industry, and layoffs among the survivors, demonstrate the technology, though promising, is not yet commercially viable. There is a growing industrial consensus that significant increases in fundamental, precompetitive research and development are essential to enable the innovation that is required if fuel cell systems are to become competitive.

Los Alamos conducts a broad-ranging fundamental research and development program for the Department of Energy's Office of Energy Efficiency and Renewable Energy, which is aimed at the necessary cost reductions, performance improvement and durability enhancements. We receive additional funding in focused areas from the DOE's Office of Science and Office of Fossil Energy and from the Defense Advanced Research Project Agency, and also directly from industry; however, no single laboratory or company can meet the R&D demands, so partnering is essential.

Mr. Moorer also described the FreedomCAR initiative where Los Alamos provides the major portion of the fundamental fuel cell R&D. I represent the laboratory as one of two non-industry members on the FreedomCAR Fuel Cell Technology Team. This team, acting under the umbrella of the United States Council for Automotive Research, provides technical comment and industry perspective on the department's technical targets and on its research and development approach through monthly review meetings.

Cooperative research and development agreements with industry, known as CRADAs, provide both technology transfer to the industry and further insights for the researchers into the barriers to commercialization, which then helps to catalyze the innovation that will lead to the next generation of fuel cells and supporting technologies. Our current CRADA partners include Motorola, Dupont and the Donaldson Corporation.

Los Alamos works with eight other national laboratories participating in the DOE hydrogen and fuel cell programs and with supporting companies, such as Superior MicroPowders represented on the panel here today. We also have placed eight coordinating university subcontracts for higher-temperature membrane R&D that are further supplemented by a subcontract with NASA's Jet Propulsion Laboratory.

For the future, the President's budget request for fiscal year 2003 contains language to initiate establishment of a fuel cell national resource center at Los Alamos National Laboratory to provide na-

tional focus and an integrated approach to addressing technical barriers to polymer electrolyte membrane fuel cell commercialization. This would be a national user facility for research and development and testing.

While the designation of a national fuel cell center and details of the center's work scope, operation and funding requirements are subject to further discussion with the sponsors, we believe the center, if established, will focus on close collaboration with industry, universities and other national laboratories, and will perform fundamental research enabling the next generation of fuel cells and related technologies that have the necessary reduced cost and higher performance and increased durability.

The center will also provide resources in the form of access to the existing knowledge base, access to experts in the field and access to state-of-the-art experimental and analytical capabilities, and it could provide a magnet for regional economic development; however, realizing this vision will require additional investment in the facility's equipment and people.

In conclusion, for more than 20 years, Los Alamos has developed the fundamental knowledge and technology innovations enabling the current generation of low-temperature fuel cells. This technology, if it can be made affordable and durable with acceptable power and energy density, will enable a truly sustainable energy future that is both emissions-free and that conserves nonrenewable resources. Our country faces ongoing and new challenges in energy, environment and economic security. Our laboratory is committed to meeting these challenges for our Nation and the world.

Finally, I would like to thank you, Mr. Chairman, for your past support. Your continued support is critical to our ability to meet the technically demanding and vital national challenges we face today and in the future.

[The prepared statement of Dr. Stroh follows:]

PREPARED STATEMENT OF DR. KENNETH R. STROH, MATERIALS SCIENCE AND TECHNOLOGY DIVISION, LOS ALAMOS NATIONAL LABORATORY

INTRODUCTION

Thank you, Mr. Chairman and distinguished Members and Staff of the Energy and Natural Resources Committee, for the opportunity to submit this report on the status of our Hydrogen & Fuel Cells Program at Los Alamos National Laboratory. I am Ken Stroh, and I've worked at Los Alamos National Laboratory for nearly 25 years on energy systems design, analysis and testing. For the last 10 years my focus has been on fuel cells, and I currently manage the lab-wide efforts on hydrogen, fuel cells and vehicle technologies for the Laboratory's Energy and Sustainable Systems Program Office.

Since 1977, the Laboratory has been performing leading-edge research on polymer electrolyte membrane, or PEM, fuel cells and supporting technologies, with primary funding from the U.S. Department of Energy (DOE). Fuel cells directly convert the chemical energy in a fuel to electricity, with higher efficiency and reduced environmental impacts compared to fuel combustion and energy conversion in conventional engines or turbines. These highly efficient power conversion systems are fueled by hydrogen, and have emissions of greenhouse gases and criteria pollutants that can approach zero when the hydrogen is made from renewable sources. Hydrogen can be derived from an array of diverse, domestic energy sources, adding to our energy security. A companion technology, the electrolyzer, works like a fuel cell in reverse, taking electricity and pure water and liberating hydrogen. Systems coupling an electrolyzer, hydrogen storage and fuel cells, if they can be made economical and durable, enable intermittent renewable energy sources, such as the sun and wind,

to drive systems that dispatch power on demand. Such systems could be ideal for off-grid power in remote locations, and would be emission-free and sustainable.

The National Vision of the U.S. Hydrogen Economy recently developed by stakeholders and the Department of Energy is compelling—"*Hydrogen is America's clean energy choice. It is flexible, affordable, safe, domestically produced, used in all sectors of the economy, and in all regions of the country.*" Fuel cells are an enabling technology for achieving this vision.

The Hydrogen & Fuel Cells Program at Los Alamos, which supports the Laboratory's mission in the area of solving ". . . *national problems in energy, environment, infrastructure and health security*," has helped advance these technologies to the point where they can be considered for broad application to our power needs, for applications ranging from cell phones, laptop computers and portable electronics, to combined heat and power for residential, commercial and industrial buildings, to transportation. In this testimony I will provide an overview of accomplishments to date, the status of the program, and challenges for the future.

BACKGROUND AND ACCOMPLISHMENTS

The focus of the Los Alamos effort over many years has been on pre-competitive fundamental research that enables knowledge-based innovation. For example, a key breakthrough enabled low-temperature fuel cells to rapidly evolve from high-cost hardware for the manned space program into a potentially viable commercial power system. The development at Los Alamos of thin-film electrode technology reduced the required precious-metal catalyst loading by a factor of 30 or more, while simultaneously improving performance. This technology is nearly universally used, and one major fuel cell component supplier even uses the trade name ELAT, which stand for "electrode Los Alamos type."

Collaboration with industry has been a characteristic of the Los Alamos program from the earliest days. In a recent letter to the Department of Energy, the Co-Director of General Motors' Global Alternative Propulsion Center stated, "*General Motors and Los Alamos have a long and successful history working together to research and develop fuel cells for automobiles. This collaboration, supported by the Department of Energy, serves as the technical foundation for the intensive development effort in fuel cells at General Motors today*." Many key players in the emerging domestic fuel cell industry trained or worked in the Los Alamos program. And, many of the first tests of pre-commercial products developed by these companies were performed at the Laboratory.

Use of hydrogen derived from reformed fossil fuels is a likely transition strategy to the ultimate renewable hydrogen economy, and Los Alamos has greatly improved low-temperature fuel cell impurity tolerance and developed key fuel-processing cleanup technology. Los Alamos used these technologies in a collaborative effort with industry leading to the world's first demonstration of electricity production in a polymer electrolyte membrane fuel cell system fueled by gasoline. Participating team members were awarded the 1997 Partnership for a New Generation of Vehicles Medal for Government-Industry Teamwork.

Fuel cells offer the potential of battery replacements and portable power systems that can be readily refueled, featuring high energy density, high reliability, low noise, and low vibration. Applications range from consumer electronics to power supplies for the defense and intelligence communities. However, hydrogen supply can be an issue for small systems. A variation of the hydrogen systems I've been discussing uses dilute methanol (commonly known as wood alcohol) as the hydrogen carrier. Methanol offers a high-density hydrogen storage medium, and can be used as a liquid fuel in the Direct Methanol Fuel Cell, or DMFC. In 2000, Los Alamos, in collaboration with Ball Aerospace, demonstrated a complete, stand-alone direct methanol power system for the Defense Advanced Research Projects Agency (DARPA) and the DOE.

In January 2001, the Los Alamos Fuel Cells for Transportation Program was selected for the Energy 100—a list of the 100 "finest scientific accomplishments" in the history of the Department of Energy. That list was then given to a distinguished Citizen Judges panel which further selected the Los Alamos effort for an Energy @ 23 Award, honoring those efforts in the 23 years of the Department that best ". . . *demonstrated benefits to the American public, a contribution to U.S. competitiveness in the global marketplace and the potential for significant future growth.*"

STATUS

Although the promise of a sustainable, clean energy future based on renewable hydrogen and fuel cells is compelling, many technical barriers remain the realizing that vision. State-of-the-art fuel cells are still too expensive, even considering cost

savings from mass production, and are still too large, heavy and fragile for widespread application. Hydrogen generation and storage present additional challenges. Continuing contraction of the fledgling fuel cell industry and layoffs among the survivors demonstrate that the technology, though promising, is not yet commercially viable.

Los Alamos conducts a broad ranging fundamental research and development program for the Department of Energy's Office of Energy Efficiency and Renewable Energy aimed at the necessary cost reduction, performance improvement, and durability enhancement. We receive additional funding in focused areas from the DOE's Office of Science and Office of Fossil Energy, from DARPA, and directly from industry (DOE's Office of Fossil Energy is developing a high-temperature fuel cell technology in parallel with the PEM effort noted here, that may be able to use hydrocarbon-derived fuels more efficiently—these systems may find technical and market advantages in stationary systems).

Today, a focus of the Department's technology development efforts is the Freedom Cooperative Automotive Research, or FreedomCAR, initiative. The transportation sector has been targeted not only because it represents about one-third of U.S. energy use and is responsible for about one-third of the domestic greenhouse gas emissions and the majority of urban pollution, but also because nearly all oil consumed in this country is used to move people and goods. And, the developing world will continue to demand increased mobility and ever increasing numbers of vehicles, with global implications for fuel use and pollution. The FreedomCAR goal is to develop hydrogen and fuel cell technologies that can enable affordable full-function cars and trucks that offer freedom from dependence on foreign oil, freedom from harmful emissions, freedom of mobility, and freedom of vehicle choice, all without sacrificing safety. I represent the Laboratory as one of two non-industry members on the FreedomCAR Fuel Cell Technology Team. This team, acting under the umbrella of the United States Council for Automotive Research, or USCAR, provides technical comment and industry perspective to the Department's technology targets and research and development approach through monthly review meetings.

An independent panel representing industry and academia also reviews the Department's research and development program annually. One comment on the Los Alamos program, from the June 2000 Merit and Peer Evaluation noted: "This effort is doing exactly what the national labs should be doing: leading the way and sharing knowledge."

Cooperative Research and Development Agreements with industry, known as CRADAs, provide both technology transfer to industry and further insight into barriers to commercialization that helps catalyze the innovation that will lead to the next generation of fuel cell and supporting technologies. The Los Alamos fuel cell effort has CRADAs with U.S. industrial partners ranging from portable electronics manufacturers to fuel cell developers to hydrogen generation developers to filtration companies. Current CRADA partners include Motorola, DuPont, and the Donaldson Corporation.

FUTURE

The President's budget request for Fiscal Year 2003 contains language to "Initiate establishment of a Fuel Cell National Resource Center at Los Alamos National Laboratory to provide national focus and an integrated approach to addressing technical barriers to polymer electrolyte membrane fuel cell commercialization. This will be a national user facility for research, development and testing." While the details of the National Resource Center's work scope, operations and funding requirements are still being determined, we believe the Center will focus on close collaboration with industry, universities and other national laboratories, and will perform fundamental research to enable the next generation of fuel cells and related technologies that have reduced cost, higher performance and increased durability. The Center will also provide resources in the form of access to the existing knowledge base, access to experts in the field, and access to state-of-the-art experimental and analytical capabilities. Ford Motor Company, General Motors and others have written letters to the Department of Energy supporting establishment of this National Resource Center at Los Alamos National Laboratory.

Our existing research and development program is housed in eight separate buildings spread across the Laboratory site. Our main activity is housed in a building that is over 50 years old and all facilities are crowded and inadequate for even the current program, let alone an enhanced national role. Working with our program sponsors in the Office of Energy Efficiency and Renewable Energy, we are studying the possibility of constructing a new building to house the Fuel Cell National Resource Center. We are currently developing the pre-conceptual design and program

information to request a Critical Decision-0 (CD-0), Justification of Mission Need, at the end of this fiscal year. If CD-0 is approved and funding obtained, we hope to perform the conceptual design work in Fiscal Year 2003. The conceptual design work in 2003 would lead to a request for Critical Decision-1. If CD-1 is subsequently approved and funds appropriated, the Laboratory could be in a position to let a design-build contract as early as Fiscal Year 2004.

If we do get the opportunity to put up a building for the Fuel Cell National Resource Center, it is the Laboratory's intent to use this facility as a pilot project in sustainable building design. Besides designing a safe, worker friendly environment where productivity is enhanced, we intend to demonstrate energy efficiency and advanced technology taking guidance from the U.S. Green Building Council's Leadership in Energy and Environmental Design, or LEED, criteria and the 21st Century Laboratories initiative of the Environmental Protection Agency and the DOE's Federal Energy Management Program. Experience shows that this whole-building design approach can deliver comparable first costs and much reduced life-cycle costs.

The Laboratory has identified a very visible and open-access building site, where visitors can see energy efficiency and advanced renewable technologies actually being used. This site is also adjacent to the Los Alamos Research Park where we expect industrial collaborators would establish local offices. We intend to make all hydrogen required for our research with electrolyzers and hope to provide the electrolyzers with electricity from a photovoltaic array, thereby demonstrating the zero-emissions renewable solar hydrogen cycle. We will consider providing building combined heat and power from a fuel cell power plant running off natural gas. Regardless of technology and features included, we intend to instrument the building as a living laboratory, where we can quantify the benefits to sponsors, visitors, and the building community. If the budget allows, we'd also like to provide a hydrogen fueling system and electric charging station for government fleet testing of fuel cell and electric vehicles.

CONCLUSION

For more than twenty years, Los Alamos has developed the fundamental knowledge and technology innovations enabling the current generation of low-temperature fuel cells. This technology, if it can be made affordable and durable, could enable a truly sustainable energy future that is both emissions free and that conserves non-renewable resources. Our country faces ongoing and new challenges in energy, environmental and economic security. Our Laboratory is committed to meeting these challenges for our nation and the world.

In conclusion, I would like to thank you for your past support. Your continued support is critical to our ability to meet the technically demanding and vital national challenges we face today and in the future.

The CHAIRMAN. Thank you very much.

Mark, why don't you go ahead with your testimony.

STATEMENT OF DR. MARK HAMPDEN-SMITH, DIRECTOR AND VICE PRESIDENT, SUPERIOR MICROPOWDERS

Dr. HAMPDEN-SMITH. Thank you. Good morning.

Senator Bingaman, thank you for this opportunity to speak before the committee this morning.

The goal of this presentation is to give a brief overview of fuel cells and their applications in general, and then focus on the specific potential of methanol fuel cells for use in remote applications of portable power.

Superior MicroPowders, or SMP as we call ourselves, is a New Mexico-based business that is providing high-performance materials for a number of energy-efficient market applications, including the fuel cell, display and lighting industries. In the fuel cell area, SMP is providing complete materials solutions, including fuel processor catalysts, as well as fuel cell stack electrocatalysts and electrode technology. More information on our products and our strategic relationships is available on our website.

SMP has been working with Motorola Labs in the development of materials for methanol-fueled fuel cells. Motorola is a leading developer of methanol-fueled fuel cell systems and the leading U.S. manufacturer of portable electronic devices. Motorola Labs previously demonstrated an early prototype methanol-fueled fuel cell two-way radio battery charger to Senator Bingaman on a recent visit to SMP.

Fuel cells are one type of a number of alternative energy technologies that have the potential to make a significant economic, strategic and environmental impact on our Nation and on the rest of the world. Fuel cells convert a fuel, such as hydrogen or hydrocarbons, and oxygen from air into water and electricity. The applications for fuel cells are generally divided into three categories: transportation applications, stationary applications and small portable applications.

The use of fuel cells for transportation and stationary applications can have a significant environmental impact by avoiding the generation of environmentally unfriendly gases produced from traditional power sources. While a potential distributed fuel infrastructure exists for stationary applications; namely, natural gas, the fuel infrastructure remains an important issue to be resolved, particularly in transportation applications.

A source of hydrogen that is not derived from fossil fuels is desirable. An excellent source of hydrogen could be water, in which case, noxious carbon-containing gases and gaseous by-products would be completely avoided. There would, therefore, be an environmental impact and a strategic impact due to the reduced dependency on foreign resources of fossil fuels; however, there is a great deal of technical development required to make this vision a cost-effective reality, which includes not only the development of fuel cell stacks and systems architecture, but also fuel-reforming, fueling infrastructure, safety, permitting, legislative issues and, most likely, an integrated technology strategy to renewable energy.

As a result, there are numerous government and State-funded programs focused on the development of fuel cells for transportation and stationary applications, and there are numerous demonstration programs to demonstrate this technology and educate the public. Our colleagues at MesoFuel, who are developing fuel-processing technology, will provide more information on the logistics of hydrogen use.

Fuel cells designed for small portable applications are in a somewhat different situation. Here, small portable fuel cells will be used to provide power for portable electronic devices, such as communications devices, including two-way radios, cell phones, personal data assistants and portable computers. In this market segment, the competing technology is battery technology, mainly secondary or rechargeable batteries. There are a number of compelling reasons for utilizing fuel cells for these applications.

From the consumer standpoint, future portable consumer electronic devices are expected to combine multiple functions, such as wireless voice and data communication, as well as computing. Current studies indicate that the power requirements of these devices will not adequately be met by current or projected rechargeable battery technologies.

From an environmental standpoint, the fuel cell could be used many times over by refueling it, and does not contain environmentally-toxic materials, unlike its battery counterparts, such as lithium ion or nickel cadmium batteries.

Logistically, fuel cells are attractive because they can be instantly recharged by adding a new fuel canister, and therefore avoiding the recharging time and carrying extra rechargeable batteries.

Furthermore, the ability to operate the electronic device remotely from the grid, because the grid is not required to recharge a battery, is, we believe, of considerable strategic value in certain applications, especially in the military and emergency service.

Finally, from a national economic benefit and strategic performance viewpoint, there is a strong driver for U.S.-based companies to take the lead in technology commercialization for portable power, a market currently dominated by foreign, mostly Asian, companies.

For small portable fuel cells, the fuel is, again, an important issue that must be addressed. Hydrogen is the best candidate from an environmental point of view, but is currently not practical due to the lack of high-energy density storage technologies for hydrogen; a similar issue exists in automotive applications of fuel cells.

Currently, methanol appears to be the most viable candidate due to its high energy density, its availability, and the technical success in operating fuel cells, either directly on methanol, or on a reformed methanol fuel feed. These factors mitigate some fueling issues; therefore, we view this area as a likely early market entry for fuel cells in general.

Government support for the development of small portable fuel cells has been mainly focused on strategic applications of small portable fuel cells for military purposes and so funded, primarily, by the Department of Defense. NIST has also addressed dual-use aspects of portable fuel cells with a few programs. Indeed, SMP has recently received two NIST ATP awards, with Motorola and others as subcontractors, as well as a DOE award for the discovery and development of automotive fuel cell stack materials.

Motorola is funded through the Army Research Lab's Cooperative Technology Alliance program to develop technology for methanol-based portable fuel cells; however, there are currently no methanol-fueled fuel cell demonstration programs with significant scope, to our knowledge. The near-term commercial potential of small portable fuel cells would be significantly enhanced by a well-supported demonstration program.

In the introduction of a broadly impacting new technology, technology demonstration programs are critical to success for both the technology developer, the end user, and for public education. The State of New Mexico is well-positioned to play a leading role in the development and demonstration of small portable fuel cell technology due to the presence of technology leaders in the State, including the national labs and a number of small businesses, a customer base with a strong need and political leadership that understands the issues involved.

We can envision a focused demonstration of portable methanol-fueled fuel cell battery chargers for two-way radios, with a cus-

tomer vehicle such as forest fire fighters in New Mexico. This customer set clearly has strategic interest to the State.

Superior MicroPowders has a leadership position in fuel cell materials technology development and Motorola has a leadership position in fuel cell system technology and commercialization and the Forest Service currently uses Motorola two-way radios and communication systems. It is envisioned that a demonstration program such as this will provide a valuable starting point for a large and nationwide developmental effort probably best administered by the Department of Energy. The execution of a demonstration program is an important step to better understand the performance requirements, packaging and demographics of device operation, as well as understand the logistics of a totally new way to recharge by refueling a portable electric power device.

The value of small methanol fuel cells in forestry applications is as follows: The rechargeable batteries used in the existing two-way radios last 8 to 10 hours between charging. In a remote location, where the electric grid is not available and transporting a traditional electricity generator is cumbersome or impractical, the rechargeable nature of the battery becomes useless. The alternative is to carry numerous disposable, or primary, batteries, or use rechargeable batteries once; therefore, the first target application for a small methanol fuel cell will be a charger that can recharge the battery and require relatively small volumes of methanol to be carried, rather than numerous batteries.

The development of a small portable fuel cell battery charger avoids the need for complex interfacing between the fuel cell and the two-way radio if the fuel cell were to be used to power the two-way radio directly.

The same concept applies to a wide variety of other remote applications for portable power, including military applications, such as homeland security or remote special forces activities, emergency services, the construction industry and hospitality services, amongst others. Lessons learned are likely to be applicable to other fuel cell applications.

So in conclusion, we feel there is an excellent opportunity for New Mexico to play a leading role in the demonstration of methanol-fueled fuel cells for remote applications of portable power through the presence of technology leaders, a strong customer base, and a strategic need.

Thank you for the opportunity to provide this testimony before the committee.

The CHAIRMAN. Thank you very much.

Dr. Godshall, you're the final witness here. We're interested to hear from you.

STATEMENT OF DR. NED GODSHALL, CEO, MESOFUEL, INC., ALBUQUERQUE, NM

Dr. GODSHELL. Thank you, Mr. Chairman, for letting me be the clean-up batter here. Seriously, we're quite honored to be here, so thank you.

I'll start off my remarks this morning, not by repeating the excellent points made by others here this morning about fuel cells, by my esteemed colleagues, Drs. Moorer, Stroh and Hampden-Smith,

but rather first touching on a point that is not as often appreciated in our national debate on energy; that is, in addition to the obviously important topic of how much energy we have, we also need to consider the quality of that energy, specifically the fact that electrical energy is more valuable to us than the same amount of energy expressed in terms of heat.

Without getting into the arcane topics of thermal mechanics and entropy, which I'm sure would bore everybody here in the room this morning, what this means is that by electrochemically extracting the energy from our limited fossil fuels, rather than burning it, as we now do almost exclusively, we can extract far more useful energy from every barrel of oil that we either import or produce ourselves, or indeed, as we're now doing, using soybeans that are grown in the heartland of America to produce that same amount of energy.

As Senator Bingaman previously pointed out this morning, fuel cells have existed for 40 years. They were a key component of America's space program in the 1960's and 1970's. Fuel cell technology and products are available today. The single largest impediment to their use, in the advent of a widespread energy economy based on hydrogen, we believe, however, is the surprisingly simple problem of distribution of the fuel to the fuel cell; distribution, not of the fuel cells themselves, in other words, but rather, distribution of the fuel, the hydrogen itself, as was discussed previously by Mark.

By analogy, imagine that no gas stations existed with which to fuel our cars today. In that scenario, the economic problems faced by Detroit in selling new cars would not be the cost of the cars themselves, but rather, the unrealistically high cost of having a gasoline tank truck come to your house every morning to put gas in your car.

The new beneficial technology of the car would therefore never have seen the economic light of day in that scenario of having no gas stations on the corner. We believe that the same is true for fuel cells at the present time. The problem in the case of hydrogen-fueled fuel cells, is the lack of low-cost distributed fuel; that is, the hydrogen, not the fuel cells themselves.

Some other technical and economical problems still exist, as has been alluded to by Dr. Mark Hampden-Smith, our colleague here at SMP, to be sure, but primarily is one of somewhat higher cost than desired by the marketplace is the cost of the expensive metal catalysts, but that economic problem is being addressed by SMP, Los Alamos and Sandia, represented here this morning. It is, therefore our belief that the primary economic barrier to widespread fuel cell use in the emerging energy economy is not the remaining cost issues with the fuel cells themselves, but the lack of distributed hydrogen.

MesoFuel is a small company based here in Albuquerque. We're focused on solving these remaining last hurdles in low-cost, on-site, on-demand generation of hydrogen when and where consumers need it. In this manner, we believe that we can be instrumental in enabling the U.S.'s transition to a hydrogen-based economy that is both more sustainable and environmentally sound, as opposed to the current hydrocarbon-based energy economy we live in today.

We do this by using new proprietary micro-scale technology to chemically convert conventional and some exciting new alternative fuels, as I mentioned, for example, soybeans, directly into hydrogen in small new products called hydrogen generators. We are looking to introduce those products later this year.

The output of our products are, therefore, pure hydrogen gas that can be supplied directly to the fuel cells to generate electricity and water. Our hydrogen generator prototypes generate hydrogens from conventional fuels, such as natural gas, propane and butane, and as I mentioned, alternative fuels, as well. We also plan to introduce products, early next year, that will generate hydrogen from gasoline, diesel, kerosene, jet fuel and other heavier hydrocarbons.

Most exciting to us, as I've alluded to, however, is our current research which shows that we will be able to generate hydrogen from sustainable renewable alternative fuels, such as the oils extracted from soybeans and other crops grown, as I said, in America's heartland. Each barrel of such oil is a barrel of oil that is not imported from politically unstable foreign markets.

Using our new meso-scale technology, we produce large amounts of hydrogen gas from a relatively small product volume. The core reactor of our first initial product is shown here. It's no bigger than the size of a stack of business cards.

Combined with the inherently greater efficiency of fuel cell technology, this process will produce much greater amounts of electrical energy from a given quantity of hydrocarbon fuels than current combustion processes. Our prototype for portable applications is not much bigger, as I said, than a stack of business cards, and our hydrogen generator for stationary residential applications fits in about the size of a cubic box about one foot on a side.

Coupled with an integrated fuel cell of equivalent 2-kilowatt power, such a system is projected to be the size of about that of a dishwasher, and can supply an average home with both its electrical and hot water needs.

MesoFuel's on-demand, on-site generation of hydrogen also innately solves another postulated problem with the emerging hydrogen economy, and that is one of safety. Competing technologies for distributing large amounts of hydrogen to local fuel cells requires large amounts of hydrogen storage at those fuel cell sites, whether that be portable, stationary or automotive applications, as discussed earlier by Mr. Moorer.

Such storage mechanisms include high-pressure-compressed gases and extremely cold liquefied hydrogen. Both of these can pose, however, significant problems should the storage container be ruptured or malfunction during fueling, especially for those automotive applications. MesoFuel's business model, however, is to generate the hydrogen on site only in the amounts immediately required by the fuel cell or other application. In this manner, no storage of hydrogen is necessary, and the safety concerns, we believe, are significantly reduced.

Additional advantages of the integrated hydrogen generator fuel cell combination are, one, both technologies have virtually no moving parts and generate no or little noise. These advantages have led to keen interest, as Mark mentioned, by both U.S. military and

commercial entities desiring either primary or backup power in a distributed environment;

Two, distributed power also now carries a homeland security component with it, since many sites around the country producing smaller amounts of electrical power will have obvious advantages over a few centralized sites producing large amounts of power, by being not as vulnerable to targeted threats;

Three, unlike batteries, again, as Mark said, the system requires neither recharging, costly maintenance nor replacement when the chemicals inside the batteries are depleted;

And lastly, four, MesoFuel's technology produces no nitrous oxide components, nitrogen oxides. Not only does our technology operate at a far lower temperature than combustion processes that produce such noxious pollutants, but our particular method of generating hydrogen uses water, interestingly, rather than air, which completely eliminates the source of nitrogen from which these nitrogen oxides are produced.

I might also just mention that MesoFuel's technology is really part of a larger effort here in New Mexico in the exciting area, realm of technology in general known as microsystems or meso-scale technology. And again, even though he didn't speak on it earlier, Dr. Al Romig, I think, represents that embodiment of that new effort here at Sandia National Laboratories, and it is rather quite exciting for the State of New Mexico.

Microsystems technology refers to a size scale that's only about the width of one to ten human hair diameters, and although this is smaller than products made by conventional machining that is current technology, it is actually larger than the size scale found in today's microelectronic chips; for example, at Intel.

This size scale and the ability to produce products in this fundamental characteristic operating size range has, nevertheless, been largely overlooked until now, we believe. MesoFuel and its parent company, MesoSystems, along with New Mexico's two national laboratories, as I said, are leading the Nation in this technology and the novel products that are now possible from it. MesoFuel's especially focused on applying this new meso-scale technology to miniaturizing hydrogen generation for the distributed power applications we've discussed here this morning.

In summary, MesoFuel believes that we can make a big impact on the way the Nation meets its future energy needs. Even though we are a very small company, we have lofty goals. Thank you for this opportunity, Mr. Chairman, to testify before the Senate Committee on Energy and National Resources and for soliciting our input and that of my esteemed colleagues here today.

[The prepared statement of Dr. Godshall follows:]

PREPARED STATEMENT OF DR. NED GODSHALL, CEO, MESOFUEL, INC., ALBUQUERQUE, NM

Dear Chairman Bingaman:

Thank you for this opportunity to speak before the Committee's field hearing this morning.

As you know, there has been great renewed interest recently in the subject of fuel cells and the role that the "hydrogen economy" can play in reformulating the way we procure and use energy in the United States. Hydrogen is the most abundant element on earth. However, the majority of this hydrogen carries with it no inherent energy content, because it is chemically combined with oxygen in the form of water.

That is, water may be thought of not in its usual way, but as "the fully oxidized form of hydrogen". And because the hydrogen is fully oxidized, we cannot "burn" it further or extract any energy from it. So let us picture water as one extreme end of a continuum of hydrogen-containing compounds that contain more or less inherent energy.

The Energy Continuum

Energy Content →

Low		High
Water (H_2O)	Hydrocarbons (C_xH_y)	Hydrogen (H_2)

Fortunately for us, not all hydrogen-containing compounds are fully oxidized. The very large class of materials known as "hydrocarbons" represent a form of hydrogen that is chemically combined with carbon. Hydrocarbons have sizable energy content, although not the maximum possible, since some of the hydrogen atoms' inherent energy is tied up with the carbon atoms. Hydrocarbons include not only the fossil fuels that we extract from the ground throughout the U.S. and the world—crude oil, coal, natural gas (and the things refined from them: gasoline, diesel, jet fuel, home heating oil, etc.)—but they also represent the basis of the foods we eat—sugars, carbohydrates, etc. In both cases, fuels and food, we "burn" these hydrocarbons in oxygen (air) to extract their remaining inherent energy content to benefit us.

Let us then contemplate the other extreme end of the above "Energy Continuum"—the case where hydrogen has not given up any of its inherent energy to other atoms chemically tied to it. This case is simply that of pure hydrogen—a gas (at room temperature and pressure) that when reacted with oxygen releases an immense amount of energy. It is this energy that is the focus of the current popular discussion about the "hydrogen economy"—not the hydrogen *per se.* When combined with oxygen to form water, hydrogen represents the ideal scenario for a fundamentally improved energy policy for America, since it represents:

- The largest amount of energy in the above Energy Continuum
- The simplest and cleanest carrier (fuel) of that energy
- The lowest pollution burden (only pure water is produced)

THE PRESENT: BURNING OF FOSSIL FUELS

Most of the world's present energy is obtained from burning hydrocarbons—the "middle ground" in the above Energy Continuum. This has successfully led the United States and the other industrialized countries through the industrial revolution of the 19th and 20th centuries, but it now poses problems for the economic growth of both the under-developed countries as well as our continued growth and energy needs. Foremost among these problems is that of environmental pollution. Not only does the burning of hydrocarbons represent less than the optimal amount of energy possible on the above Energy Continuum, but it also contributes to "global warming", since the "carbon half" of the hydrocarbon is turned into carbon monoxide and carbon dioxide during the burning process. To make matters worse, some of the nitrogen present (from the air) during such burning of fossil fuels leads to harmful nitrogen oxides. Similarly, sulfur present naturally in many fossil fuels is also oxidized during such burning, and directly leads to "acid rain".

THE FUTURE: DIRECT CONVERSION OF HYDROGEN

The reaction of pure hydrogen with oxygen, however, results in none of these environmental problems. The only byproduct (pollutant) of the reaction that need be produced is pure water. Changing the country's energy policy to one based on a "hydrogen economy" would therefore not only result in a greater amount of useable energy than the equivalent amount of hydrogen in the fossil fuel hydrocarbons that we extract from the ground, but would also greatly reduce the environmental burden associated with our energy use.

THE QUALITY OF ENERGY

A critical point that is often overlooked in the present debate is the quality of the energy that is produced in both scenarios. Presently, the first thing that we do with nearly all fossil fuels extracted from the ground is that we burn them. This burning process extracts the inherent energy in the fuel—but it unfortunately does so in a

manner that represents the lowest possible form of that energy—heat. Imagine another continuum, this time one describing the quality of energy, rather than the amount of energy:

The Energy Quality Continuum

Energy Content →

Low ____ High

Heat Motion Electricity

Electricity represents the highest form of a given amount of energy; heat, the lowest form of that same amount of energy. The motion of, say, a car or a vacuum cleaner motor represents an intermediate form of that same amount of energy. A quick illustration will demonstrate the point that the same amount of energy has different "qualities" associated with it: we know that in our homes we can turn on our electric stove tops and convert electricity from our local power company into heat by boiling a pan of water. However, the converse is not true—we cannot take that same energy (in the boiling water) and easily convert it back into electricity to power our vacuum cleaner. Any energy generation process is therefore far more useful if it directly results in electricity rather than heat.

Fuel cells powered by hydrogen do just that—they directly convert the energy content inherent in the hydrogen fuel into electricity. They do not burn it, as we presently do with 99% of all fossil fuels extracted from the ground for energy use today. Stated differently, even if the above-described benefit of a future "hydrogen economy" over our present "hydrocarbon economy" did not exist—just this "direct conversion to electrical energy" point alone could represent huge cost savings and reduced foreign oil imports over the present situation. Presently, we burn fossil fuels in our cars and our homes and most of our power plants. By doing so, we immediately reduce the fuel's inherent energy content to its lowest form. Then, we are forced to extract back only a small fraction of that energy in relatively inefficient mechanical devices, such as the engines in our cars and generators in our power plants.

A car, for example, utilizes only about 15% of the inherent energy in the gasoline with which we fuel it. That is because we burn 100% of it immediately, reducing the gasoline to its lowest possible form—and then we convert about 15% of that heat back into motion through the pistons in the engine to make our cars go down the road. The remaining 85% of the energy is lost as heat, which is why we need the radiators in our cars to cool the engine from all the lost heat. A fuel cell powered car, conversely, directly converts the fuel's inherent energy into electricity without burning it and without this innate degradation of the energy. This direct conversion to electrical energy could represent huge cost savings and reduce foreign oil imports over the present situation. Even just a 5% increase in the country's energy efficiency through such direct energy generation would represent millions of barrels of oil that need not be imported.

SO WHAT'S THE PROBLEM?

So here we have a great new technology: hydrogen—a simpler form of energy with a higher energy content than an equivalent amount of hydrocarbons, one that can be easily converted into a higher and more efficient form of that energy (electricity) when coupled with a fuel cell, and one that has virtually no pollution or environmental drawbacks! So what's the problem? Why is it not here already?

The problem, as with any new technology, is economics. Technology does not a business make. Until the economics of fuel cells and the hydrogen economy become cost competitive with the present hydrocarbon economy, these technologies will remain only intellectual curiosities and research laboratory pursuits.

Fuel cells have existed for 40 years. They were a key component of America's space program in the 1960s and 1970s. Fuel cell technology and products are widely available today. The single largest impediment to their use, and the advent of a widespread energy economy based on hydrogen, we believe, is the surprisingly simple problem of distribution. Distribution not of the fuel cells themselves, but rather distribution of the fuel—the hydrogen itself.

By analogy, imagine that no gas stations existed with which to fuel our cars. In that scenario, the economic problems faced by Detroit in selling cars would not be the cost of the cars themselves, but rather the unrealistically high cost of having a gasoline tank truck come to one's home each time the car's gas tank ran empty. The new beneficial technology of the car would never have seen the economic light

of day in that scenario. We believe that the same is true for fuel cells at the present time. The problem in the case of hydrogen-fueled fuel cells is the lack of low-cost distributed fuel—hydrogen—not the fuel cells themselves.

Some other technical and economic problems still exist, to be sure, with widespread fuel cell sales and acceptance—primarily the one of somewhat higher cost than desired by the marketplace due to the cost of expensive metal catalysts. But that economic problem is being addressed and solved by fuel cell manufacturers and their suppliers, for example through the development of electrode micropowders that perform better while actually using much less of the expensive metals. One such important developer, *Superior MicroPowders*, is another local New Mexico company based here in Albuquerque, and another panelist here this morning, Dr. Mark Hampden-Smith, is SMP's V.P. and co-founder. These remaining fuel cell technical and cost hurdles are also being addressed and solved by New Mexico's two national laboratories, *Sandia National Laboratories* and *Los Alamos National Laboratory*, represented here also this morning by Drs. Al Romig and Ken Stroh, respectively.

MESOFUEL, INC.

The primary economic barrier to widespread fuel cell use and the emerging hydrogen energy, therefore, is not the remaining cost issues with the fuel cells themselves, but the lack of distributed hydrogen. MesoFuel is focused on solving this remaining last hurdle—the low-cost, on-site, on-demand generation of hydrogen when and where consumers need it. In this manner, we believe that we can be instrumental in enabling the U.S.'s transition to a hydrogen-based energy economy that is both more sustainable and environmentally sound.

We do this by using new proprietary micro-scale technology to chemically convert conventional and alternative fuels directly into hydrogen in small new products, called Hydrogen Generators, that we are introducing later this year. The output of our products is pure hydrogen gas that can be supplied directly to the fuel cell to generate electricity and water. Our Hydrogen Generator prototypes generate hydrogen from conventional fuels such as natural gas, propane, and butane. We also plan to introduce products early next year that will generate hydrogen from gasoline, diesel, kerosene, and jet fuel. Most exciting to us, however, is our current research, which shows that we will also be able to generate hydrogen from sustainable, renewable, alternative fuels such as oils extracted from soy beans and other crops grown in America's heartland. Each barrel of such oil is a barrel of oil that is not imported from politically unstable foreign markets.

Using our meso-scale proprietary technology, we produce large amounts of hydrogen gas from a small product volume. Combined with the inherently greater efficiency of the fuel cell technology, this process will produce much greater amounts of electrical energy from a given quantity of hydrocarbon fossil fuels than current combustion processes. Our prototype for portable applications is not much bigger than a stack of business cards, and our Hydrogen Generator for stationary/residential applications fits in a cubic box about one foot on a side. Coupled with an integrated fuel cell of equivalent 2 kW power, such a system is projected to be the size of a dishwasher, and could supply an average home with both its electrical power and hot water needs.

MesoFuel's on-demand, on-site generation of hydrogen also innately solves another postulated problem with the emerging hydrogen economy: safety. Competing technologies for distributing large amounts of hydrogen to local fuel cells require large amounts of hydrogen storage at the fuel cell site, whether that be portable, stationary, or automotive applications. Such storage mechanisms include high pressure compressed gases and extremely cold liquefied hydrogen. Both can pose significant safety problems should the storage containment be ruptured or malfunction during fueling, especially for automotive applications. MesoFuel's business model, however, is to generate the hydrogen on-site only in the amounts immediately required by the fuel cell or other application. In this manner, no storage of hydrogen is necessary, and the safety concerns are significantly reduced.

Additional advantages of the integrated Hydrogen Generator/fuel cell are:

- Both technologies have virtually no moving parts and generate no noise. These advantages have led to keen interest by both the U.S. military and commercial entities desiring either primary or backup power in a distributed environment.
- Distributed power also now carries a homeland security component with it, since many sites around the country producing smaller amounts of electrical power will have advantages over a few centralized sites producing large amounts of power, but vulnerable to targeted threats.
- Unlike batteries, the system requires neither recharging, costly maintenance, nor replacement when the chemicals inside the batteries are depleted.

- MesoFuel's technology produces no nitrous oxide pollutants (NO_X). Not only does our technology operate at a far lower temperature than combustion processes that produce NO_X pollutants, but our particular method of generating hydrogen uses water rather than air, which completely eliminates the source of nitrogen from which NO_X is produced.

MICROSYSTEMS TECHNOLOGY

MesoFuel's technology involves an exciting new realm of technology known, in general, as Microsystems (or meso-scale) technology. Microsystems technology refers to a size scale that is about the width of only 1 to 10 human hair diameters. Although this is smaller than products made by conventional machining, it is actually larger than the size scale found in today's microelectronic chips. This size scale, and the ability to make products in this fundamental characteristic operating size range, has nevertheless been largely overlooked until now. MesoFuel, and its parent company MesoSystems—along with New Mexico's two national laboratories—are leading the nation in this new technology and the novel products that are now possible from it. MesoFuel is specifically focused on applying this new mesoscale technology to miniaturizing hydrogen generation for distributed power applications.

MESOFUEL'S RECOMMENDATIONS TO THE ENERGY COMMITTEE

- The primary need is for hydrogen and hydrogen generation technology, and the need for sustained and significant investment in these issues by DoE. Most of the present research and development money is going into fuel cells and fuel cells cars, not hydrogen generation. Government investment in hydrogen generation and hydrocarbon reforming will have a far bigger impact on fuel cell adoption rates than additional funds applied to either fuel cells or cars.
- Long-term government tax relief incentives, such as those used to support the wind power industry twenty years ago, would support faster adoption of fuel cells and accelerate the commercial viability of the industry.
- Future U.S. energy policy should incentivize both the private and public sectors towards significant clean air and alternative/renewable energy economies. The reaction of hydrogen with oxygen, especially when occurring electrochemically in a fuel cell, represents the cleanest and most environmentally benign process imaginable for intelligent use of scarce natural and renewable resources. The prospect of significantly reducing harmful nitrogen oxides, for example, should be strongly encouraged in the 21st century. Similarly, the prospect of reducing foreign oil imports through incentivized development and use of renewable fuels such as soy diesel, methanol, and ethanol to produce hydrogen should be equally encouraged by U.S. energy policy.

In summary, MesoFuel believes that we can help make a big impact on the way the nation meets its future energy needs. Thank you for this opportunity to testify before the Senate Committee on Energy and Natural Resources, and for soliciting our input and that of my esteemed colleagues here today.

The CHAIRMAN. Well, thank all three of you for excellent testimony.

Let me ask Dr. Stroh first, your—you say you are on the board that's involved with development of the FreedomCAR, as I understood your testimony.

Dr. STROH. I'm on the fuel cell technology team for FreedomCAR, yes.

The CHAIRMAN. The fuel cell technology team. What is the time frame that is being considered there for actual development of a commercially available fuel cell-powered car?

Dr. STROH. The targets for complete market competitiveness are on the order of a decade. There are interim targets and there will be, you know, functionally appropriate products, that could go into Government fleet demonstrations and other fleet markets where you don't have to put in broad infrastructure because fleets have limited operating range and tend to have a centralized support, in much nearer-term.

Some of the foreign companies are talking about leasing fuel cell vehicles to governments in the next year or two.

The CHAIRMAN. And those fuel cell vehicles foreign companies are going to have available in the next year or two, how are they powered? What is the source of the hydrogen that——

Dr. STROH. Well, nearly all the vehicles that are out there in test situations, such as the California fuel cell partnership, are powered by direct hydrogen on board, either as compressed gas, or in some cases, stored on board as liquid hydrogen or in metal hydrides.

There are a few vehicles out there with on-board reformers for—DaimlerChrysler has one with methanol. General Motors has one with gasoline, so there are vehicles of all types out there, but the vast majority of things you might see in the press releases are hydrogen vehicles.

The CHAIRMAN. Let me try to get straight in my own head here the various applications that people have in mind for fuel cell technology.

I think, Mark, you referred to it in your testimony as a transportation application, which is the FreedomCAR, and the various others that we just talked about; a stationary application where you would put a unit in a home, for example, that would provide power for the home; a third would be the small portable applications; and is there a fourth, or is that—are those the three that——

Dr. HAMPDEN-SMITH. I think that covers it, yeah.

The CHAIRMAN. I guess I'm concerned, from the little I know about this, that the priority that we have established by making this FreedomCAR the sort of flagship effort with regard to fuel cell development, the priority we've set is in that area, the transportation application, and that is the most difficult and the farthest in time from being actually feasible, and some of these other things are getting short shrift, which might actually produce much nearer-term results that would then help us in developing the FreedomCAR or other applications.

Do you have any views on that, Dr. Stroh?

Dr. STROH. Yes, I do, and I'm sure my colleagues do, as well.

You're right in that the transportation application is like doing the hardest problem first. In order to be in your vehicle—mine's parked outside—it's got to be cheap, light, small, put up with very little maintenance, operate in all kinds of environmental conditions, and rapid start-up, all those kinds of things. The thing is, if you can do that transportation application, all the other applications are available to you because their constraints are less.

You can pay several times the dollars per kilowatt for stationary application that you can for transportation, but there are trade-offs there, too. You'd like a stationary application to last much longer than you would a transportation system, so there are different challenges in each application.

The thing that's common, which I think argues against the idea that one application is getting the short end, is that the materials and the types of construction in all these devices are very similar, even comparing hydrogen fuel cells and liquid methanol fuel cells. The materials at the heart of the electric chemical conversion are the same, and in fact, the transportation program, under FreedomCAR, actually funds work at Los Alamos on few-watt direct methanol fuel cell systems because that may be one of the very earliest market applications, it may be the place the consumers

first get used to relying on fuel cells and buying fuel cells. It maybe be the first applications that lead to mass production of the core material, and therefore, it is enabling for the transportation application.

I think the reason that you see the bulk of the effort oriented toward transportation is that's where we use oil, and anybody that uses energy has issues with emissions and efficiency of the fuel source, but transportation, we use most of the oil we use in this country. And so I think it's reasonable for that to have a very high priority.

The CHAIRMAN. Let me ask, Mark, did you have a comment on where we're putting our emphasis in the research and development of these different applications?

Dr. HAMPDEN-SMITH. Yes, I think so. I don't think I actually completely agree with everything Dr. Stroh just said. I think actually, it's perhaps the other way around. I think it was a very clever thought of the DOE to go after the most demanding, the highest-cost target market because that drives the rest of the industry. So if you look at some of the cost targets, I mean, full adoption of fuel cell cars has the cost around $50 a kilowatt, maybe $30 a kilowatt, I think, as we heard earlier today. That's extremely demanding.

A stationary residential fuel cell has a cost target of full market adoption of $500 a kilowatt, so as we've seen actually in the industry, a lot of the car companies are now looking at providing stationary fuel cells because they realize they can get revenue on the way to making a car. You could look at Toyota, they've got stationary residential fuel cell programs.

And actually, at the other extreme, if we all grab our little cell phones, of course, if we pay $100 for our long-life lithium ion battery, and it puts out a watt, that's $100,000 a kilowatt. That's the math. So, which market supports the earliest entry point? Probably this one, because we're already paying a $100,000 a kilowatt. So I think, actually, from the beginning, to have an aggressive target on the most demanding application is absolutely the right thing to do.

I think, as the technology develops, I think there's a lot of leverage in what's being developed in terms of reforming, in terms of electrocatalysts; you can pick up the other markets on the way there, so perhaps now it is time to look at some of those other market opportunities and getting some government support for that, but actually, it is happening. I think DOE has a solicitation coming out in the residential fuel cell area, so I think, through all the good lobbying that's going on and good information that's being exchanged between private industry, the national labs and politicians, you know, the vision is being shared, and I think the direction is being taken.

Of course, we have a particular interest in wanting to see something perhaps go more into the direct methanol area or methanol fuel, in general, because—or maybe support that fuel being separated, but there is a market need, why, we're all currently paying well above the prices of fuel cell——

The CHAIRMAN. Dr. Godshall, did you have a point of view?

Dr. GODSHELL. Yeah. Thank you.

I think it is an excellent point to raise and so I'll just try—I agree with everything he said, so I'll just try to add one other com-

ponent to it, if that's helpful to the committee, and that's to put some numbers on these three markets you've identified without getting into engineering.

The portable market, I think that's obvious to everybody, is, obviously, much smaller than the transportation need in your car, but what's not as well-appreciated is the residential application. That middle market we've talked about is actually considerably smaller in the actual size of that one unit, that one application, so to put numbers on them, the portable application, like Mark just mentioned, is on the order of .1 kilowatt. A car takes on the order of 100 to 150 kilowatts, and what's surprising there now, to most people, is that a home only takes 2 to 5.

So a car takes, in terms of power, takes anywhere from 75 to 100 times that of the power it takes to run your home. And although that surprises people at first, the reason for that is really quite obvious, and that is, you're not trying to drive your home down the highway at 60 miles an hour, so the only point that I'm really trying to be helpful with here, is, first of all, is that the residential market, which we are targeting because it is closer to approach, it is the nearer time, as you suggested, Senator, is also an easier and more near-term market physically, just because its application is the size of the unit that we may make or the size the fuel cell is can be up to 100 times smaller than the equivalent of that amount of power that you need to run your car down the road.

The CHAIRMAN. Well, as I say, I guess my concern is that as we are focused on the hardest problem, and that may be a good strategy from the point of view of pushing the envelope, as far as development of technology, it may not be the right strategy as far as getting fuel cell technology utilized, and I'm wondering if we're going to end up essentially ceding to foreign competitors the nearer-term market in fuel cell-related, technology-related applications while we are focused on helping develop the FreedomCAR somewhere down the road. Is that——

Dr. GODSHELL. That absolutely is our belief. Now, again, I remind everybody again that there is—it's somewhat self-serving for us to say that because that is the business model we have taken, but we've taken it for the very reason you've said, Senator. We believe it's a very near-term and much more plausible avenue to tackle the more doable things first. Some of our competitors have indeed taken the opposite approach, and that is go directly to the automotive market, which, as Dr. Stroh said, is admitted by all that are knowledgeable in the field is a much more difficult, much more long-term task, so you're absolutely right.

It's our belief that what we should have been picking is the more portable and residential applications, not only because they're near-term and partly what you suggested, that we don't miss the boat, and so, absolutely, we concur that as long as it's well-balanced, all three of these markets, in terms of fuel cells, obviously, need some attention by the research and Government funding sources, but yes, we do believe that perhaps the smaller—physically smaller applications have not gotten as much attention.

The CHAIRMAN. Mark, let me ask you, you are focused on using methanol as the fuel to operate these fuel cells. What is the reason

that is chosen over other sources? I gather that there's some advantage to that. Maybe it's just the thing that you are sure——

Dr. HAMPDEN-SMITH. In general, without being here for 3 hours, the use of fuel cells and the fuels that fuel them is going to be extremely application-specific. I mean, let's look at those three areas, I mean, briefly, and let you get kind of a better feel for why people are choosing different technologies.

Actually, we make materials for fuel cells powered by natural gas, hydrogen and methanol. It just happens that methanol is particularly suitable for this particular market for portable power. But if you go back and look at the transportation area, you've only got two choices; you can say I'm going to use this infrastructure that fuels all our cars today, and "I'm going to put some device on the car that converts the gasoline that I would put into it," or some other fuel, "into hydrogen that runs the fuel cell," and I think DOE, in consultation with all the car companies, are saying, "Well, gee, that's unlikely to be realistic because of the issues of a fuel processor to run such a big fuel cell small enough I'm not going to be able to fit it in the car." So they've immediately taken the burden out of, perhaps, developing the fuel cell for the car to making that problem more the hydrogen infrastructure for the automotive application. So that's one issue, as I see it. Chances are, fuel cell vehicles are going to be fueled by hydrogen, and it's going to be reformed off-site, somewhere else.

Now, in the stationary application for homes, and that would be—stationary fuel cells could be 250 kilowatts, the nice thing about stationary fuel cells is, if you run them off natural gas, the fueling infrastructure already exists, for the most part, or you could run them off liquid propane, for example, or some other fuel that is commonly distributed, so stationary fuel cells are probably closer to the market because there's no logistic fueling infrastructure issue in the sense of where I do get the fuel from. Most of our homes will be plumbed with natural gas.

If you want to make a very small fuel cell, you're really faced with two choices: You've either got to use some kind of fuel, then reform it, which means two-way radios are a little bit larger. There's a better value proposition in the emergency services and military for having that instantly, we can all probably carry around—afford to carry around a couple batteries, but what I'm faced with is either having a fuel processor—the fuel processor on board on this thing, which is generally unviable, or I've got to put hydrogen on here, but there's no real good way to store hydrogen. It's very energy-inefficient and cost-inefficient.

So methanol has a higher energy content than hydrogen, because it's a liquid, primarily; it has a lot of energy content in it compared to gas, H2, so it can be stored very efficiently, at a very high volume, and actually, a direct methanol fuel cell does two things at once: the fuel cell itself is its own reform, its own fuel processor, so the same materials in that fuel cell convert the methanol to hydrogen and then the hydrogen, the protons do the rest of the chemical reaction, so actually, a direct methanol fuel cell has in the fuel cell an on-board reformer.

That's why you want to use a fuel like methanol; it can be converted to hydrogen at relatively low temperatures by the same cat-

alyst that would split the hydrogen into protons to react with oxygen and make electricity. So methanol's a good fuel of choice. Actually, ethanol would be better, but it's tougher, technically. Ethanol would be better from an energy and density point of view, but methanol now is the fuel of choice for small fuel cells because you can use the same catalyst to both reform the methanol and convert it.

The CHAIRMAN. Okay. That's very useful. That's a very good description.

Let me just ask one other question about this technology demonstration program for small portable methanol fuel cell battery chargers.

Dr. HAMPDEN-SMITH. That's a mouthful.

The CHAIRMAN. Is that all accurate that——

Dr. HAMPDEN-SMITH. Yes.

The CHAIRMAN [continuing]. That's what your view, Mark, is, that we should give that a priority both because it's not getting a priority, but also because this is a very readily achievable application that has commercial potential; is that accurate?

Dr. HAMPDEN-SMITH. Yes, it is. Here's our thought. We can't take credit for it, a lot of other people have had the same thought, and I think people who are making other small fuel cells for small electronic devices are definitely going down the path of don't-replace-the-battery integration issues associated with getting the fuel cell to integrate directly with an electronic device, but rather keep recharging the battery; recharge the battery.

It was Motorola, I think, that thought it up. But a lot of people are thinking about that for that reason. I think one reason that we see this as a very good market opportunity is it will be good for fuel cells, in general. I think fuel cells need to be brought to the attention of the general public. There's a lot of information floating around about them, but it's all mainly transportation-focused, and as everybody says, that it's kind of miles off in the future, you know, is it going to happen, is it going to happen.

On the other hand, I don't think you should go out and expect, in a year, to see all our cell phones being fueled by fuel cells because it doesn't make any business sense to go after the market that's most demanding as your first target market. So we have teamed with Motorola for that specific reason, we make the materials, they have the market entry point, and they have a systems integration capability in a market where there's a very strong need for the type of capabilities a fuel cell recharger would supply.

So, for example, if you could—the two-way radio the Forest Service uses, or emergency services use are relatively large, one would envision having built a holster that is a direct methanol or even reformed methanol fuel cell that would trickle-charge the battery. The reason there's a very good business proposition for this, the math works out that if you wanted to power these two-way radios for the week, which is typically the time a forest firefighter fights a fire, they need about 80 watt hours, that's about seven NiCd batteries. So they're carrying seven NiCd batteries. It's equivalent—even including 21 percent efficiency on converting the methanol to electricity, that's about 70 millileters of methanol. It's about this much. So what would you rather do, have your two-way radio bat-

tery being constantly recharged by your holster, and carry small amounts of methanol, or carry seven relatively bulky batteries.

These folks are paying a lot of money for a battery, so there's a good economic value, too, and actually, you know, methanol, under certain circumstances, is a flammable substance. Who better to manage that in an early demonstration program than firefighters. So, for a lot of reasons, it really, to us, makes a lot of sense, and I think, actually, more than that, I think getting this technology out in the marketplace and getting people familiar with it and talking about it, and if it goes into emergency services, it can probably go into the hospital—I mean it'll start to infiltrate lots of other markets and that's typically how these markets learn about, you know, advanced technology. So that's our view on the situation.

The CHAIRMAN. Either of the rest of you want to make a comment on the appropriateness of giving priority to this development of a battery charger?

Dr. Stroh, did you have a follow-up?

Dr. STROH. I think that that's a good first market to look at. I think there are opportunities in other markets, as well, to do early demonstrations, to get these things out, in use, get the public used to them, do some education around them, do some Government first-buys that generates a revenue stream that keeps some of these companies going.

One point that does back up your concern about the way we're headed in this country is the fact that in just the last 3 or 4 months, a couple of rather innovative companies have closed doors because if you're looking at revenues being 5 to 7 years out, small companies can't stay alive that long, so we need to find ways to get some early markets going, get revenue coming into these companies, and at the same time as the products get out there, people get familiar with them, kids learn about them in school, they start to generate some market pull where the benefits are realized, and you can bootstrap the market up from there.

The CHAIRMAN. All right. Well, this has been very useful. Thank you all very much for the testimony, and we will try to take this record and educate some of our colleagues about the value of both solid-state lighting and fuel cell technology and hydrogen generation technology and hope that we can do some good with the information in the next Congress.

Thank you all very much. That will conclude our hearing.

[Whereupon, at 11:40 a.m., the hearing was adjourned]

[Subsequent to the hearing, the following statement was received for the record:]

STATEMENT OF NATIONAL ELECTRICAL MANUFACTURERS ASSOCIATION LIGHTING DIVISION SOLID STATE LIGHTING SECTION

INTRODUCTION

The National Electrical Manufacturers Association (NEMA) Solid State Lighting Section appreciates the opportunity to present testimony before the Senate Committee on Energy and Natural Resources regarding solid-state energy efficient lighting technology.

The testimony will focus on the following areas: introduction of the NEMA Solid State Lighting Section to the Committee; the need for solid-state lighting technology in commercial and consumer applications; the operational characteristics of solid-

state lighting technology; and finally, encouraging investment and development of sold state lighting technology.

THE NATIONAL ELECTRICAL MANUFACTURERS ASSOCIATION SOLID STATE LIGHTING SECTION

The NEMA Solid State Lighting Section is comprised of 13 member companies representing various market segments that manufacture semiconductor light sources, products, and systems for specialty and general lighting applications. The Solid State Lighting Section is one of several sections within the NEMA Lighting Systems Division. NEMA is proud to represent such a dynamic and growing lighting technology field.

The National Electrical Manufacturers Association is the largest trade association representing the interests of U.S. electrical industry manufacturers. Our more than 400 member companies manufacture products used in the generation, transmission, distribution, control and use of electricity. NEMA works to advance the interests of member companies in the areas of government affairs, standards and economics. Annual shipments of member goods exceed $100 billion in value, and these firms employ over 400,000 workers in the United States.

The NEMA Solid State Lighting Section is tasked with integrating the dynamics of solidstate light sources into existing lighting practices, and to create new practices to fully utilize the potential of solid-state lighting technology. In this regard, the section includes all related downstream users including application, controls, and power necessary for the effective utilization of solid-state light sources. This also includes building and maintaining a center of expertise, creating a definition of terms, and coordinating activities with other sections within the NEMA Lighting Systems Division. It also includes working with other NEMA sections outside of the Lighting Division, and recognized policy and standards setting organizations.

While the NEMA Solid State Lighting Section recognizes many topics of concern to section manufacturers, a primary interest is the integration of solid-state lighting technology into existing lighting practices and systems. While research and development on solid-state lighting technology are worthy goals, the NEMA Solid State Lighting Section also believes in end-use applications as an important goal.

THE NEED FOR SOLID STATE LIGHTING TECHNOLOGY

Solid-state lighting technology is a significant part of the future of energy-efficient lighting. The U.S. public and private sectors have undertaken strategies to reduce our energy consumption through the development, promotion, and application of energy-efficient lighting products and systems. While significant achievements have been realized, further important energy savings are possible with technical breakthroughs that would result in the application of solid-state lighting systems in general lighting markets. It is estimated that adoption of solid-state technology could reduce global electricity usage for lighting by 50 percent, and reduce global electricity consumption by 10 percent over the next twenty years.

Expanding on this analysis, it has been estimated that lighting represents about twenty to thirty percent of electrical use in the United States. Furthermore, the best illumination systems on the market today convert about twenty-five percent of electricity into light. A report in *Scientific American* from February 2001 estimates that if white light emitting diodes (LEDs) could be made to match the efficiency of red light emitting diodes, they could reduce energy needs and cut the amount of carbon dioxide pumped into the air by electrical generating plants by 300 megatons a year.

Solid-state lighting holds tremendous potential for the environment. It has been estimated that the United States could avoid 200 metric tons of carbon emissions by 2020 if solid-state lighting garners a significant share of the general lighting market. There are also economic benefits in terms of employment, growth, and in supplier and equipment industries.

The numbers and analysis all lead in the same direction and eventual conclusion: solid-state lighting technology is a significant part of the future of energy efficient lighting. Indeed, the future holds the potential benefit of long-lasting, durable light emitting diodes that burn less energy and emit virtually no heat as compared to their lighting counterparts. Solid-state lighting technology is the next generation of lighting technology and deserves the attention of American policymakers and energy consumers.

THE OPERATION OF SOLID STATE LIGHTING TECHNOLOGY

Light emitting diodes are only a few tenths of a millimeter in size. They are essentially semiconductor materials that convert electrical energy into light. They con-

sist of semiconductor crystals grown layer by layer, with the crystal layer emitting a characteristic colored light when electricity is passed through it.

According to material in the February 2001 edition of the *Scientific American*, the modern goal for light emitting diodes is making pure white light. This helpful article provides an easier grasp of solid-state lighting technology, and identifies two main ways of generating white light. The first is "color theory" where the light output from LEDs of red, green, and blue wavelengths are combined to make white light. However, research has shown that it is difficult to truly mix the colors of the LED to achieve uniformity and control. The second way relies on an LED photon to excite a phosphor. For example, one can package a yellow phosphor around a blue LED. When the energy of the LED strikes the phosphor, it becomes excited and gives off yellow light. This mixes with the blue light form the LED to give white light. Alternatively, an ultraviolet light LED can be used to excite a mixture of red, green and blue phosphors to give white light. This process, similar to that in fluorescent tubes, is simpler than mixing three colors, but is less efficient due to absorption and scattering factors.

THE PRESENCE AND BENEFITS OF SOLID STATE LIGHTING TECHNOLOGY IN EVERY DAY APPLICATIONS

Light emitting diodes convert electricity to colored light more efficiently than a common incandescent bulb available on today's market. They are rugged and compact with some types of LEDs lasting up to 100,000 hours. This translates into approximately a decade of regular use. In contrast, the average incandescent bulb lasts about 1,000 hours.

Light emitting diode technology is everywhere: from cell phone faces and automobile dashboards to bigger applications in buildings and memorials. To better understand the reallife applications of sold-state LED technology, it is helpful to look at a bustling commercial enterprise like the NASDAQ in New York City, and the refurbishment of the venerable Jefferson Memorial in Washington, DC. In both situations, planners used solid-state lighting technology with striking results. At the NASDAQ headquarters on the NASDAQ Marketsite Tower, the worlds largest video screen uses 18,677,760 LEDs covering 10,736 square feet. At the Jefferson Memorial, Osram Sylvania used more that 17,000 LEDs to illuminate a quote from Thomas Jefferson that was hard to see under the old lighting conditions. Jefferson's famed quote—now brightly lit—encircles the inside of the vaulted rotunda at the base of the dome: "I have sworn upon the altar of God eternal hostility against every form of tyranny over the mind of man."

Light emitting diode technology can also be found in exit signs, traffic signals, edge and backlit lighting for signage, accent lighting for buildings and marker lighting (e.g. airplanes or theaters), or landscape lighting when low-level lighting is used to show the way in darkened areas. In Europe, LEDs are being used in the majority of cars produced there for high mount brake lights. The United States is moving in that direction as well; light emitting diodes are being used in taillights, turn signals and side markers for trucks and buses. LEDs also have intriguing applications in medical science and museum curator applications.

LED's low heat, flexible strips and even wavelength promises reliability and wide applications.

ENCOURAGING INVESTMENT AND DEVELOPMENT OF SOLID STATE LIGHTING TECHNOLOGY

The NEMA Solid State Lighting Section strongly supported the Next Generation Lighting Initiative (NGLI) as described in S. 517/H.R. 4. While good progress was made on the legislative language, it fell prey to a crowded end-of-session calendar.

The NEMA Solid State Lighting Section believes the language passed by the Senate as part of the comprehensive energy bill (S. 517) in the 107th Congress will provide the necessary resources to overcome the pre-competitive research and development hurdles associated with white light illumination using solid-state light emitting diodes. Modeled after successful past initiatives, it will enable manufacturers to address those problems associated with such technological development, with the ultimate goal of end-use application of solid-state lighting technologies.

With regard to federal appropriations dollars, within their limited resources, the Department of Energy has shown support for solid-state lighting research and development. The NEMA Solid State Lighting Section wrote to key appropriators and urged the full funding for the NGLI in fiscal year 2003 as described in the authorizing language. The Section supports full funding for the Next Generation Lighting Initiative, and appreciates the commitment by members of Congress to achieve that end.

The NEMA Solid State Lighting Section stands ready to work with interested legislators, policymakers and other stakeholders to pass and enact language for a Next Generation Lighting Initiative.

CONCLUSION

The NEMA Solid State Lighting Section appreciates the opportunity to address the Senate Committee on Energy and Natural Resources concerning solid-state energy efficient lighting. The section hopes that the foregoing introduction and discussion of solid-state lighting technology, and the subsequent discussion of the need for investment in the end-use application of the technology, will reinforce the benefits of energy efficient lighting technology to the Committee.

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